Operational Feasibility of Segmented Independent Parallel Aproaches

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Abstract—**Noise, especially in the vicinity of airports, is one of the most important factors of modern air transport systems, especially at mayor hub airports. New approach designs like curved Required Navigation Performance (RNP) procedures to independent parallel runway systems can decrease the noise footprint in sensitive ground areas without reducing airport capacity.**

So far, only straight-in ILS (or MLS) approaches are allowed for independent parallel approach operations. To introduce RNP curved/segmented approaches as a further option for independent approaches to a parallel runway system, a safety concept has been developed by DLR in recent years based on the ICAO SaRPS for independent parallel approaches (ICAO Doc 9643). Following this concept, curved RNP approach operations should be possible at Frankfurt/Main airport enabling noise abatement even in high density traffic situations.
This paper considers the operational aspects of independent segmented parallel approach procedures at major airport-hubs with parallel runway systems like Frankfurt Airport. It reports about a new route design enabling the management of mixed aircraft equipage. The focus is on the operational feasibility of the new TMA design. This has been assessed by a real-time simulation with controllers of the German Air Navigation Service (DFS). The results of these simulations are presented in this paper.

Keywords: Independent Segmented approaches; Noise abatement; Real-time Simulation; Required Navigation Performance (RNP)

I. INTRODUCTION

Different forecasts predict a global growth of air traffic within the next decades [1], [2]. In the next 20 years air traffic will double, leading to an increase in noise pollution [1]. But aircraft noise is already now a major constraint at many airports. Increase in airport capacity can often only be achieved if noise abatement measures are taken to protect people living around the airport [3]. Here, the German Frankfurt/Main Airport can serve as a perfect example. In course of introduction of the forth runway, many measures to reduce aviation noise and thus the burdens resulting from it in the Rhein-Main region have been set into operations. Those measures attempt to avoid or reduce noise [4] directly at the source, or to ensure a more even distribution of the noise burden. Besides technical measures on the aircraft [5] which reduce the noise generated by the aircraft itself, noise abatement can also be achieved by operative measures based on altered/optimized flight profiles, flight procedures, routes etc. which reduce the level and/or the effects of the flight noise generated and/or increase the distance between the emission source and the immission location. To decrease the noise impact by increasing the distance between the aircraft generating the noise and noise sensitive areas on the ground is one of the most promising approaches. This can be achieved either by lateral avoidance of such areas (see e.g. [6] and [7]) or by a higher vertical flight profile. A good overview of possible vertical profiles and their effect on noise reductions is given in [8] and [9]. Studies on steeper approach profiles and how they can be implemented into today's approach operations are addressed in [10], [11], [12], and [13].

This paper deals with the lateral option of enabling active noise abatement. Curved or segmented approach as discussed in e.g. [6] or [7] show great potential to enable approach paths above ground areas with fewer residents. Such a procedure has already been implemented successfully for Frankfurt Airport as an RNAV GPS approach (Figure 1.).
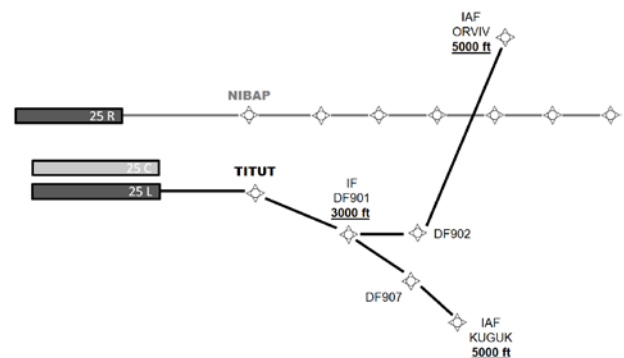

Figure 1. RNAV GPS Segmented approach to Frankfurt RWY 25L

However, there are some regulatory constraints to this procedure. Neither the ICAO nor the FAA published the use of curved approach paths for an independent parallel approach in their documents so far. But independent approach operations on the parallel runways are required in Frankfurt to match the traffic demand. So this new segmented approach is only used in night times after 23:00 h.

New approach procedures based on Advanced RNP or RNP-AR [14] over the possibility to overcome these constraints under certain circumstances. In [15], [16], [17], we developed and calculated a safety concept for segmented independent parallel approaches based on the ICAO guideline for independent parallel approach. In section II of this paper, some basic considerations about the safety concepts and procedure design are summarized; detailed calculations can be found in [15], [16], [17].

The main topic of this paper is about a real time simulation campaign to prove operational feasibility (section III, IV and V). During this campaign at DLR's Air Traffic Management and Operation Simulator (ATMOS) in autumn of 2016, the operational feasibility was verified by six Frankfurt approach controllers. The main purpose of that campaign was to assess the impact of segmented independent parallel approach procedures on the controllers' work.

II. INDEPENDENT APPROACH OPERATIONS TO PARALLEL RUNWAYS USING SEGEMENTED APPROACHES

ICAO Doc 9643 describe important prerequisite of independent parallel approaches. It prescribes that independent approach procedures are permitted only with straight-in precision approaches. Usable navigation methods are the Instrument Landing System (ILS) and the Microwave Landings System (MLS). Other navigation systems and approach procedures with curved segments are non-compliant with the ICAO standards.

For an independent parallel approach, a vertical separation of 305 meters (1000 feet) or more is required between both approaches. If both aircraft are established on their localizers or MLS final approach tracks, the vertical separation can be reduced to less than 305 meters (1000 feet), as illustrated in Figure 2. A normal operating zone (NOZ) and a non-transgression zone (NTZ) are required by [18], if the vertical separation is less than 1000 feet. The NOZ describes the area in which the aircraft operates normally, while the NTZ, located between both runways, must not be entered. The NTZ is monitored by a precision radar controller called the precision runway monitor (PRM)
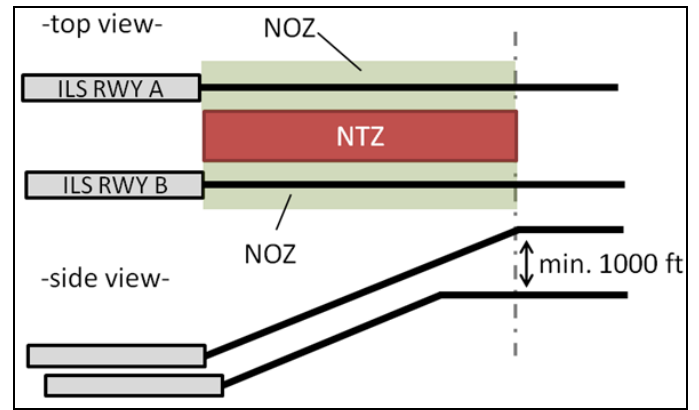

Figure 2. NTZ/NOZ concept based on [18]

If this controller detects an aircraft leaving the NOZ, he can give instructions to the blundering aircraft or ask the threatened aircraft to initiate a breakout maneuver. The radar monitoring accuracy and update rate for the detection of deviating aircraft depends on the runway separation according to [18]. Runway separations between 1036 meters (3400 feet) and 1311 meters (4300 feet) require a radar accuracy of 0.06 degrees in azimuth, a display system with deviation warnings and a radar update rate of minimum 2.5 seconds.

However, many mayor airports with a parallel runway system do have by far bigger distances between their parallel runways than the required minimum of 1036 m (3400 ft). For example, the distance between the two approach runways 25R and 25L at Frankfurt Airport is about 1918 meters which gives an extra buffer w.r.t the above mentioned dimensions of NTZ. Combining this extra buffer with the new capabilities of RNP AR approaches or advanced RNP approaches including radius-to-Fix (RF)-capabilities, independent approach operations should be possible even if one the approaches is not an ILS but an RNP approach including RF legs.

In [15], [16], [17] a generic safety case for such independent operations has been developed and new layout and dimensions for the NTZ for curved and straight-in approaches have been designed. Further on, new requirements for minimum distance between parallel runways have been calculated if a RNP curved approach is used simultaneously to a straight-in precision approach on a parallel runway. The calculations have been based on a RNP approach with a RF-turn onto the extended centerline of the runway not exceeding 30°. The following table (Table I) summarizes these requirements on minimum runway spacing.

TABLE I. MINIMUM RWY SPACING

Guidance on straight approach	Guidance on curved approach	Required minimum RWY spacing
ILS	RNP AR APCH (RNP 0.1)	1200 m
ILS	RNP AR APCH (RNP 0.3)	1750 m

Following this considerations, the noise abating RNAV segmented approach procedure (see Figure 1.) has been redesigned as an RNP procedure. This procedure consists of two 24° radius-to-fix turns with radii of 4 nautical miles between DF720 and DF719 as well as between DF718 and SEGFA, as illustrated in Figure 3. Analogue to the ILS approach, a three degree glide path angle was set for the curved approach. The lateral navigation accuracy can be ensured by the Required Navigation Performance concept with an accuracy of RNP AR APCH 0.3 respectively RNP AR APCH 0.1.
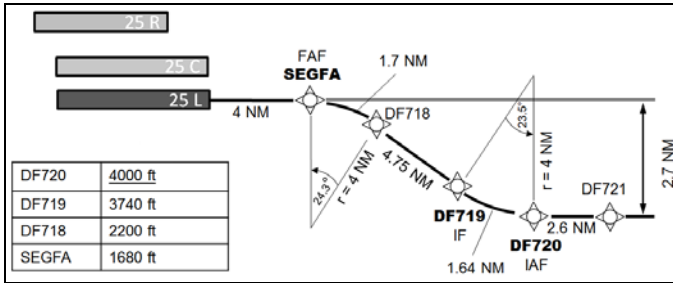

Figure 3. New RNP route design

RNP 0.1 is based on a predefined performance level, which is prescribed to the aircraft in 95 percent of the total flight time. In case of RNP 0.1 the aircraft have to stay in a flight corridor of ± 0.1 nautical miles (about ± 185 meters) for this period [19]. RNP AR APCH additionally requires that in more than 1*10-7 approaches a flight corridor of 2xRNP (0.2 nautical miles) must not be exceeded [18].

For the execution of RNP AR approaches, special training of the crew, safety assessments as well as the certifications of the aircraft are needed for each procedure. Nevertheless, RNP AR APCH is used for the proposed procedure because it is currently the only procedure for segmented approaches with radius-to-fix turns. Advanced RNP, a concept of tomorrow could also be applicable as it also supports RF legs. At the same time, the complexity of the procedure is significantly reduced with advanced RNP [19].

A. Redesign of Frankfurt TMA route structure

The actually approach design for Frankfurt Airport is based on independent parallel approaches with a northern and a southern trombone structure. In order to ensure a vertical separation of 305 meters (1000 feet) between both runways, aircraft on the southern trombone intercept the localizer at an altitude of 1219 meters (4000 feet), whereas aircraft on the northern trombone intercept their Instrument Landing System (ILS) localizer at 1524 meters (5000 feet). If both aircraft are stabilized on their localizer, a NTZ is established to reduce the vertical separation below 305 meters (1000 feet). Without

instructions from the controllers, aircraft follow the entire trombone structure. Minimized flight distances and efficient separations between consecutive aircraft are generated by vectoring the aircraft out of the Trombone. If controllers use this option, they must ensure that either a vertical separation of 305 meters (1000 feet) or a lateral separation of at least 5556 meters (3 nautical miles) is maintained. In addition, the track angle to the localizer should be less than 30 degrees [18].

As it can be seen from Figure 1, the new approach procedure is not integrated into this approach route structure. To do so, as few changes as possible should be introduced to the basic working concept of approach controllers at Frankfurt airport. Especial, the basic concept of a trombone structure should be retained. Furthermore, the new route structure should support the management of traffic with mixed equipage. Not every aircraft will be RNP 0.3 or even RNP 0.1 equipped within the next couple of years. In addition, it should be easy to switch to ILS only operations in case of low visibility (CAT 1 or worse).

To do so, an alternative to the RNP approach is required allowing a standard conventional ILS approach. The considerations resulted in a new approach route structure that can be seen in Figure 4. The core part of this structure is a so called parallelogram. This parallelogram ensures that flight aircraft need flying either way is approximately the same. Therefore, separation between two aircraft established before entering the parallelogram will remain after the parallelogram even if these two aircraft fly different pathes of the parallelogram. A divergent route guidance, starting at the new waypoint "FRATO", allow a curved RNP approach above a less populated area as well as the classic but shortened ILS approach via the final approach point (FAP) "LEDKI".
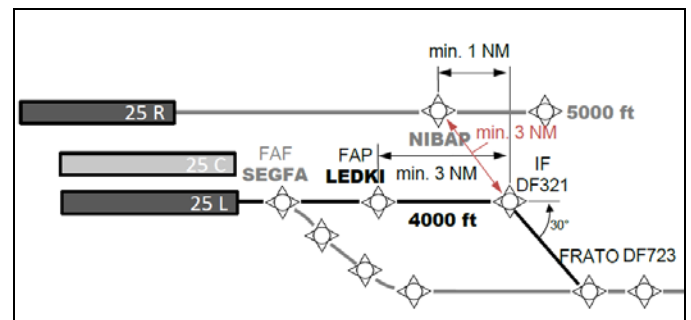

Figure 4. New approach route structure enabling mixed equipage traffic

Due to an expected maximum noise reduction, the segmented approach is initially planned for RWY 25L. The segmented approach shifts the entire trombone about 5000 meters (2.7 nautical miles) to the south, while preserving the original shape. The ILS route follows a RNAV transition, which intercepts the localizer with exactly 30 degrees at the intermediate fix (IF) "DF321". The positioning of the waypoint FRATO is essentially dependent on the ILS route guidance.
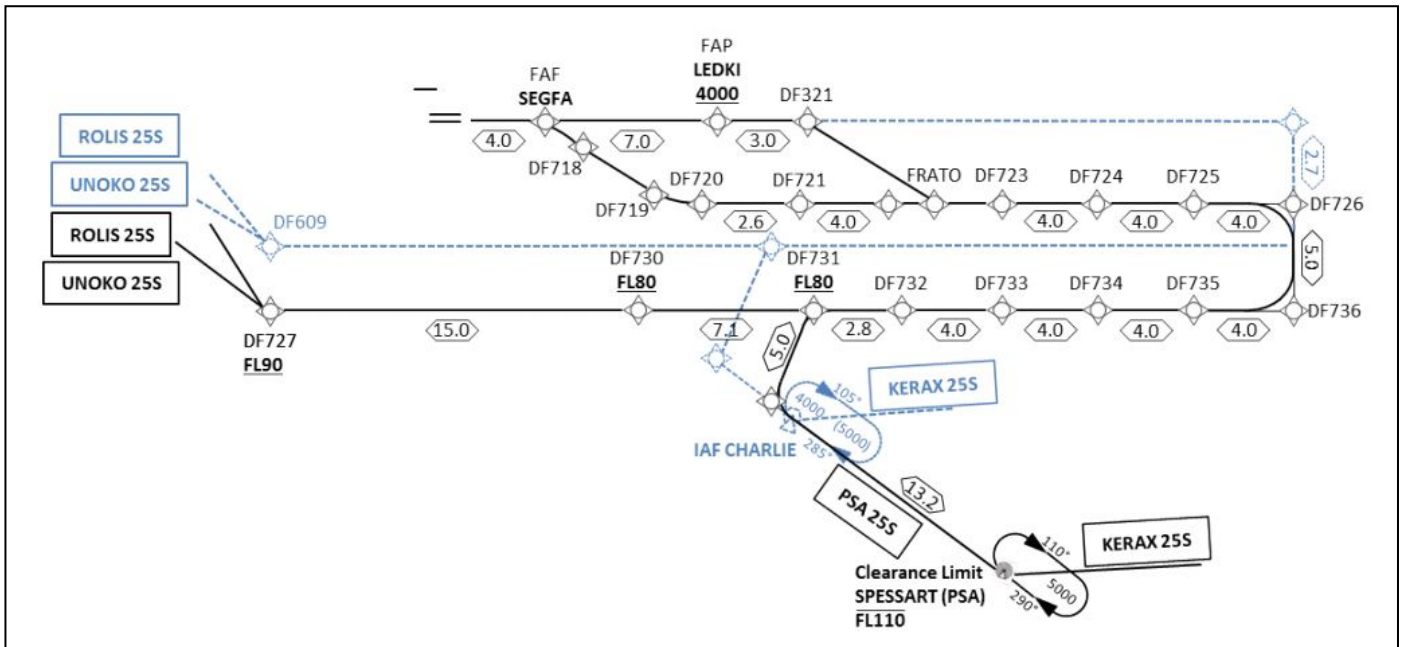
Figure 5. Modification of old TMA route structure to accommodate the new final approach path design

ICAO document 9643 prescribes a minimum of one nautical mile straight ahead flight to intercept the localizer, before the vertical separation between both parallel runways can be reduced below 503 meters (1000 feet) [18].

In addition [20] requires an at least two nautical miles level flight to capture the glideslope. At all a 5556 meters (3 nautical miles) straight ahead flight is required between the FAP "LEDKI" and the IF "DF321" [20]. It must also be ensured that the vertical separation of 305 meters (1000 feet) or the lateral separation of 5556 meters (3 nautical miles) is maintained until aircraft on both runways are established [21]. Aircraft on the segmented approach begin with a continuous decent of three degree at waypoint "DF720". The lateral route guidance takes place via two 24 degree radius-to-fixed turns with radii of 7408 meters (4 nautical miles), connected by a 8797 meters (4.75 nautical miles) straight ahead flight. All in all, the new route structure (colored black) was only slightly changed compared to the old structure (colored blue), as illustrated in Figure 5..

III. REAL-TIME SIMULATION

In autumn 2016, six Frankfurt Airport approach controllers of the German Air Navigation Service (DFS) were part of a two-week real-time simulation at the German Aerospace Center (DLR) in Brunswick. The main focus was to evaluate the suitability for daily use from the controllers' point of view.

To guarantee a realistic working environment, the Air Traffic Management and Operations Simulator (ATMOS) was modified for Frankfurt Approach. Particularly, the design of the radar and weather displays including the background color and aircraft labels as well as the paper flight strips were customized. The two controller stations for Pickup and Feeder were connected via radio communication with each two pseudo-pilot stations. Main assignment of the pseudo-pilots was to simulate the pilots' communication and to navigate the aircraft on basis of the controller specifications. Each pseudo-pilot had to handle several aircraft at the same time.

Especially the divergent route guidance for aircraft with different RNP-equipment and the abridged trombone structure took center stage. For this, the real-time simulation based on six scenarios with two different flight plans, a low traffic flight plan (2013) and a high traffic forecast flight plan (2022), each with three different percentages of RNP-capability (50%, 80% and 100% segmented approach), as shown in Table II.

TABLE II. SCENARIO DETAILS

Scenario	Scenario details	
	Flight plan	RNP-capability
1	2013	50 % segmented approach
2	2013	80 % segmented approach
3	2013	100 % segmented approach
4	2022	50 % segmented approach
5	2022	80 % segmented approach
6	2022	100 % segmented approach

The simulation was accompanied by four different questionnaires. The "profile" questionnaire collected all personal information about the controller such as age, work experience as an Approach Controller and the years of experience. After each scenario, the "post-scenario" questionnaire gathered information about the scenario handling on both controller stations. Depending on the working position

(Feeder or Pickup controller) the controllers had to rate five statements on a Likert-type scale. As an additional survey method, AIM and SASHA questionnaires developed by Eurocontrol were used to evaluate the workload and the situation awareness in the previous scenario. The "change" questionnaire after all scenarios at the same controller position measured, which was the most / least demanding scenario at this position. The concluding "final" questionnaire included generally questions about the object of study and the simulation rating. As an example, the controllers had to evaluate the behavior of the aircraft and pseudo pilots as well as the working environment in ATMOS.

In addition to the questionnaires, each controller had to use the computer-based survey ISA, Instantaneous Self Assessment, during the scenarios. On a scale between 1 and 6, the controller had to choose his perceived current workload every five minutes.

Simulation-sided, many performance data were collected in each scenario. The behavior of the simulated aircraft, the interaction between the controllers as well as between controller and pseudo-pilot and the flight paths including headings, altitude and speed, are just some of them.

IV. RESULTS OF THE REAL-TIME SIMULATION

The six DFS controllers had an average age of 39.3 years. They all work as an Approach Controller at Frankfurt Airport with an average of 15.7 years of experience.

The data evaluation shows a high rate of pseudo pilot accuracy in all scenarios and runs with approximately 99.0 % correct command realizations. The evaluation was carried out for all incorrect command implementations which had repercussions on the aircraft as well as no subsequent adjustment during a time range of 30 seconds after the wrong initialization.

Based on the low traffic flight plan 2013 and the forecast high traffic flight plan 2022, the controllers had to handle 21 aircraft or 24 aircraft in 45 minutes, respectively. Notwithstanding the above, the controllers achieved a high average capacity of 27 aircraft across all scenarios and runs. Main reason was the primary structure of the real-time simulation. Without departures on runway 25C and 18W it was possible to minimize separation on final. The missing arrivals on runway 25R and the resulting lack of communication between both airspace controllers was an additional factor.

Overall, the controller performance was on a very high level of quality. On the divergent routes between FRATO und SEGFA no significant deviations of separation could be detected between aircraft on the same flight path as well as the divergent flight paths. As an example, the flight tracks for all runs of the sixth scenario are shown in Figure 6.
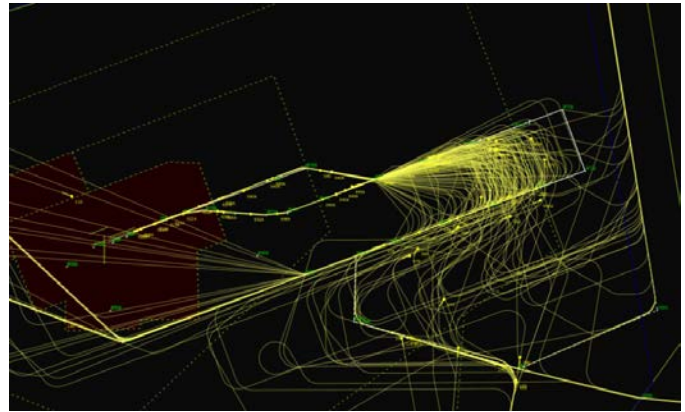

Figure 6. Flight tracks scenario 6 all runs

Based on the higher separation between the parallel approach paths, it was permitted to use higher altitudes than 1219 meters (4000 feet) between the waypoints DF726 and FRATO. Approximately 88.6 percent of all simulated aircraft reached 1219 meters (4000 feet) more than four nautical miles before FRATO.

At the Feeder position the effort "…taken to build up an efficient separation on Final", "…to monitor separation between the divergent routes (FRATO and SEGFA)" and "…to ensure minimum separation at all times", was in acceptable limits in all scenarios. For most controllers, the route distance between FRATO and SEGFA as well as the distance between DF726 and FRATO seem to be enough. The Likert-type scale shows that the high traffic scenario 4 with 50% RNP-capability was the hardest for the Feeders.

At the Pickup position the effort "…taken to achieve an efficient separation at DF731", "…to hand over new aircraft to the Feeder at the right moment", "…to assess the Feeder's workload" and "…to make sure that the Feeder managed a workable number of aircraft" was within acceptable limits in all scenarios.

All controllers rated that the route distance between PSA and DF731 is enough to achieve an efficient separation for low traffic scenarios 1 - 3. Two and three controllers collected "disagree/somewhat disagree" for scenario 6 and scenarios 4 / 5, respectively. Main reason was the high level of aircraft at the beginning of these scenarios, eleven aircraft versus four aircraft in scenarios 1 - 3.

Altogether, Scenario 4, high traffic with 50% RNP-capability, as well as high traffic scenarios 5 and 6, were the hardest for the Pickup controllers.

The AIM questionnaire, Assessing the Impact of Automation on Mental Workload, is divided into eight scales (1) - (8). Each scale contains four questions.

(1) Building and maintaining awareness

(2) Monitoring of information sources

(3) Memory management

(4) Managing the controller working position

(5) Diagnosing and problem detection

(6) Decision making and problem solving

(7) Resource management and multi-tasking

(8) Team awareness

Scales (2), (4) and (8) were excluded for tailor-made AIM to reduce the time required after each scenario. The scales (2) and (4) were excluded because the simulation target should not evaluate an information system or a controller working position. Scale (8) was also excluded because each scenario was implemented by only two controllers, the Pickup and the Feeder.Each question (in total 20 questions) could be rated with seven possible answers: none, very little, little, some, much, very much, extreme, which corresponds to numbers from 0 to 6. Accordingly the overall score can be between 0 and 120 for tailor-made AIM. The lower the overall score, the lower was the mental workload.

The AIM-Feeder results show a very low level of workload for all six scenarios with an average rating between "very little" and "little". There were no significant effects of traffic and/ or RNP-capability. The Pickup controller gave higher ratings for the high traffic scenarios 4 – 6, as shown in Table III.

TABLE III. TAILOR-MADE AIM RESULTS OF FEEDER AND PICKUP CONTROLLER

Scenario	Feeder controller		Pickup controller	
	Average	*sum / 20*	*Average*	*sum / 20*
1	26.50	1.33	20.17	1.01
2	21.33	1.07	18.00	0.90
3	25.00	1.25	22.50	1.13
4	31.50	1.58	37.17	1.86
5	30.67	1.53	36.50	1.83
6	30.00	1.50	36.17	1.81

Nevertheless all ratings were relatively low in all six scenarios. There were no main effect of RNP-capability or interaction between RNP-capability and traffic. With average ratings between 21.3 and 31.5 points per scenario for the Feeder and 18.0 and 37.2 points per scenario for the Pickup, the results were in the lower third of the tailor-made AIM questionnaire, as illustrated in Figure 7.
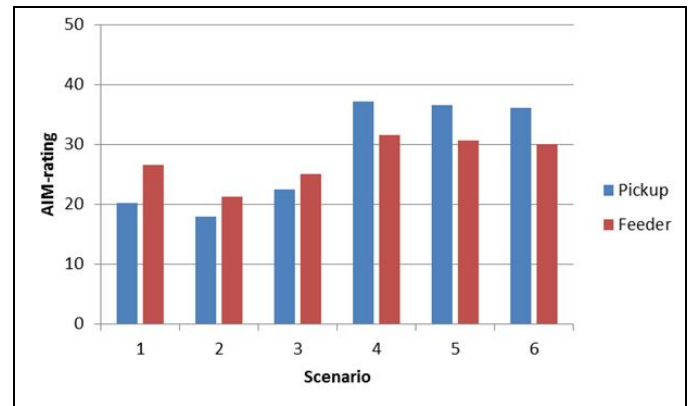

Figure 7. Results of tailor-made AIM for Pickup and Feeder controller

SASHA questionnaire, designed by Eurocontrol, uses six statements to calculate the overall situation awareness for each controller position in all six scenarios. The six sentences could be rated as: never, seldom, sometimes, often, more often, very often and always, which corresponds to a number from 0 to 6. Thus the maximum overall score is 36 points. The higher the overall score, the higher was the situation awareness of the controllers.

The SASHA-Feeder ratings were very high with overall scores between 32.0 and 34.3 points per scenario. These correspond with an average rating between "very often" (5 points) and "always" (6 points). Significant main effects of RNP-capability and / or traffic were not detected, as shown in Table IV.

TABLE IV. SASHA RESULTS OF FEEDER AND PICKUP CONTROLLER

Scenario	Feeder controller		Pickup controller	
	Average	*sum / 6*	*Average*	*sum / 6*
1	33.00	5.50	35.50	5.92
2	32.83	5.47	34.67	5.78
3	34.33	5.72	34.83	5.81
4	32.33	5.39	32.67	5.44
5	32.83	5.47	30.83	5.14
6	32.00	5.33	32.67	5.44

Accordingly the AIM questionnaire, the Pickup controllers gave lower ratings for the high traffic scenarios 4 - 6 than those for scenario 1 - 3. Overall, all ratings were very high (between 30.8 and 35.5 points), with an average rating between "very often" and "always" like the SASHA-Feeder ratings. Main effects were indicated in relation to the scenario traffic only. Neither effects of RNP-capability nor interaction effects between traffic and RNP-capability could be detected, as illustrated in Figure 8.
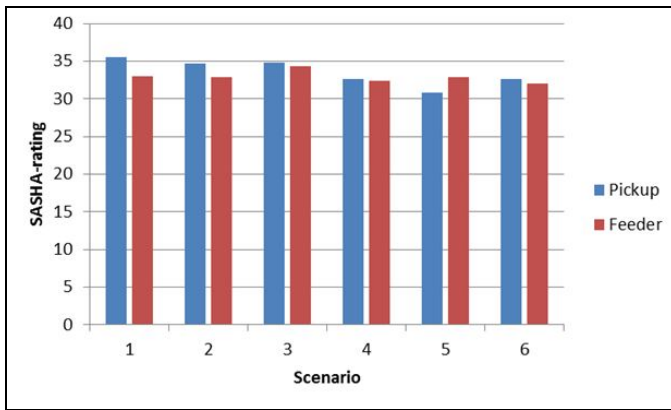
Figure 8. Results of SASHA for Pickup and Feeder controller

In accordance with the results of SASHA, all controllers (Feeder and Pickup) rated the question "How would you rate your overall situation awareness during the scenario?" between "good" and "very good".

ISA measured similar results as the tailor-made Aim questionnaires. For the Feeder working position as well as the Pickup working position, significant effects were detected in relation to the scenario traffic. With regards to the RNP-capability as well as the interaction between RNP-capability and traffic, no significant main effects were identified, as shown in Table V.

TABLE V. ISA RESULTS OF FEEDER AND PICKUP CONTROLLER

| Scenario | Controller position | |
	Feeder – Average workload ISA	Pickup – Average workload ISA
1	1.81	2.31
2	1.86	2.06
3	1.94	2.10
4	2.96	2.89
5	2.98	2.62
6	3.01	2.96

On a scale of 1, very low workload, to 6, very high workload, the average workload was between 1.81 and 2.31 for the low traffic scenarios. The average workload for the high traffic scenarios was slightly higher between 2.62 and 3.01. At all, all ratings for mental workload are relatively low in all low traffic scenarios and on a normal working level in the high traffic scenarios, as shown in Figure 9.
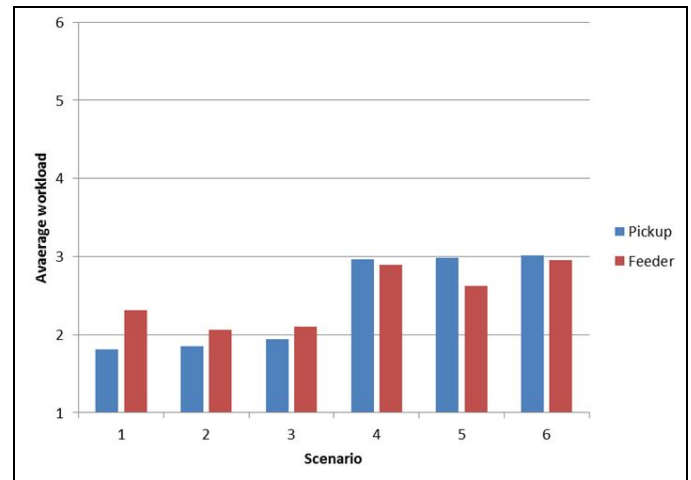

Figure 9. Results of ISA for Pickup and Feeder controller

After all six scenarios in the same position, the controller had to rate which scenario was the least demanding and which was the most demanding. All controllers (Feeder and Pickup) felt the high traffic scenarios 4 – 6 as the most demanding. Three Pickup and three Feeder controllers chose scenario 4 (high traffic and 50% RNP-capability) as the most demanding scenario at all.

For 4 out of 6 Feeder controllers and 5 out of 6 Pickup controllers the scenarios with less traffic were the least demanding, two each chose scenario 1 and scenario 2, five controllers chose scenario 3 (low traffic and 100 % RNP-capability) as the least demanding one.

The "change questionnaire" results confirmed the sentence ratings of AIM and SASHA, although scenario 4 was also the hardest one.

The initial controller assessment clarified that the procedure is suitable for Frankfurt International Airport with capacitive limitation of five to six aircraft simultaneously at the Feeder position. Beside this, the controllers estimated the required average practice time between two and three days before the procedure could be implemented in Frankfurt.
Altogether, each three controllers "agree" / "somewhat agree" with the sentence "I can imagine myself working with this procedure". Furthermore three controllers "somewhat agree", that the procedure adds a disproportionate amount of workload to the controller. This suggests some general acceptance issues or issues with the procedure itself.

In the second part of „final" questionnaire, most controllers assessed the behavior of the aircraft and the pseudo pilots as realistic. Likewise, four out of six controllers found that the working environment in ATMOS was fit for purpose. The other two controllers "somewhat agree" with these statement. In total the working environment as well as the behavior of the aircraft and pseudo pilots did not affect the simulation data.

V. Conclusion

Previous research has demonstrated that curved RNP approaches can be operated independently from straight-in ILS approaches on a parallel runway system given that the distance between the two runway exceeds a certain threshold. According to this consideration, Frankfurt airport seems to be suited to introduce such operations. The aim of this research was to design a TMA route structure that enables the use of an RNP curved approach on RWY 25L independently of ILS straight-in approaches on RWY 25R. The main component of the new design was a so called parallelogram structure which enabled the use of an curved RNP for noise abatement together with standard ILS operations on RWY 25L if aircraft equipage ofr low visibility conditions do not allow for the usage of the RNP curved approach. Operational feasibility of the concept have been assessed successfully by a two week real-time simulation campaign. The real-time simulation results show that an approach design with divergent routes is suitable for Frankfurt Airport. All controllers reported low levels of workload and very high levels of situation awareness at all time for each scenario. Capacity restrictions could be detected for the Feeder position only. A close cooperation between the Pickup and the Feeder controller can ensure that the new concept design does not lead to capacity bottlenecks. Even though all ratings were relatively low for tailor-made AIM and relatively high for SASHA the controllers' self-assessment was less high relating to the procedures workload and situation awareness. This suggests some general acceptance issues or issues with the procedure itself. Further real time simulations are foreseen to reveal and address these issues.

Based on subjective measurements, it was shown that the percentages of aircraft with RNP capabilities haven't any influences on the controllers' workload and situation awareness, likewise the combination between the RNP capability and the traffic mix. Differences between the scenarios were only detected for the Pickup between the high-traffic and low-traffic flight plans. The high traffic scenarios were more demanding for the Pickup controllers work, than the low traffic scenarios.

A consideration of all scenarios shows that scenario four (future high traffic and 50% equipage rate) was the most stressful for all six controllers. Regardless of the scenario, traffic flow should be managed such that the feeder should control a maximum of five to six aircraft at the same time.

The small test sample merely represents a general tendency. Further studies, including larger samples, will provide additional insights.

Necessary real-time simulations for further research involve a complex simulation with independent parallel approaches and departures on all runways. Special effects such as wind influences, blunder scenarios, "Go Around" procedures and speed reductions on the divergent route offer test scenarios under real-life conditions.

References

[1] AIRBUS, 2016, Global Market Forecast: Mapping Demand 2016/2035, Blagnac Cedex, France.

[2] BOEING, 2016, Current Market Outlook 2016-2035, Seattle, United States of America.

[3] Wörner, J. D.; Research on less noisy aviation – a tour d'horizon about possibilities and limits; 2nd International Conference on Active Noise Abatement; Frankfurt Airport; 2013.

[4] Gebauer, P.; Ockel, ; First Package of Measures for Active Noise Abatement at Frankfurt/Main Airport; http://www.forum-flughafen-region.de/fileadmin/_migrated/content_uploads/FFR_Report_Active_Noise_Abatement-July_2010_engl..pdf.

[5] Delfs, J.; Test research on the reduction of aircraft noise at source; 2nd International Conference on Active Noise Abatement; Frankfurt Airport; 2013.

[6] Mollwitz, V.; Using RNP AR for Noise-Abating Approach Procedures; Deutscher Luft- und Raumfahrtkongress 2012, Berlin, 2012.

[7] Többen, H. et. al., Flight Testing of Noise Abating RNP Procedures and Steep Approaches. Journal of Aerospace Engineering, SAGE Publications Ltd. ISSN 0893-1321.

[8] Isermann, U.; Potentials and limits of noise abatement flight procedures; Internoise 2013, Innsbruck, Austria, Sep. 2013.

[9] Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center) DLR: Leiser Flugverkehr – zusammenfassender Projekt-Abschlussbericht (Quiet Air Traffic - Final Report), Göttingen (2004).

[10] Denegery, D. G. et al.; Flight Evaluation of Three-Dimensional Area Navigation for Jet Transport Noise Abatement, Journal of Aircraft, Vol 10, No. 4; April 1973.

[11] Hamel, P.; Dahlen, H. W.; Erprobung lärmmindernder Anflugverfahren mit dem DFVLR-Forschungsflugzeug HFB 320; DFVLR-Nachrichten, Heft 10, July 1973.

[12] Mollwitz, V.; Korn, B.; Steep Segmented Approaches for Active Noise Abatement – a Flyability Study; ICNS 2014, Herndon, April 2014.

[13] Mollwitz, V.; Korn, B., Flight Testing Steep Segmented Approaches for Noise Abatement. DASC 2014, 04.-09. Okt. 2014, Colorado Springs, USA.

[14] ICAO, 2008, Required Navigation Performance Authorization Required Procedure Design Manual, Doc 9905, Montreal, Canada.

[15] Hanses, C., 2013, An initial safety concept for segmented independent parallel approaches, ICNS-Conference 2013, Herndon, Virginia.

[16] Hanses, C., 2013, A safety concept paving the way towards segmented independent parallel approaches, In: IEEE Aerospace and Electronic Systems Magazine, 29 (5), p.34-39.

[17] Hanses, C., Korn, B., 2015, Designing segmented independent parallel approach procedures for a mixed-equipage environment, ICNS-Conference 2015, Herndon, Virginia.

[18] ICAO, 2004, Manual on Simultaneous Operations on Parallel or Near-Parallel Instrument Runways (SOIR), Doc 9643, Montreal, Canada.

[19] EASA, 2009, Airworthiness Approval and Operational Criteria for RNP Authorization Required (RNP AR) Operations, Brussels, Belgium.

[20] ICAO, 2014, Procedures for Air Navigation Services – Volume II Construction of Visual and Instrument Flight Procedures, Montreal, Canada.

[21] Speijker, L., Couwenberg, M., Kleingeld, H., 1997, Collision risk related to the usage of parallel runways for landing, Amsterdam, The Netherlands.

[22] Korn, B.; Finck, T.; Mollwitz, V., Hanses, C.; Stelkens-Kobsch, T., Independent curved approach procedures – safe and feasible?, 4th International Conference on Active Noise Abatement ICANA 2016; Frankfurt Airport; 2016.

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