Flight Trial Evaluation of Automated Paired Approaches onto Closely Spaced Parallel Runways

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Abstract – In this contribution the existing RPAT concept for simultaneous approaches to closely spaced parallel runways is further elaborated to be implemented in low visibility. Besides RNP capabilities this concept uses as well airborne interval management capabilities. The basic procedure design aspects and the required airborne functions are described. The airborne spacing will first be initiated by a 4D approach in which the trajectory of the target aircraft is being predicted based on position information provided by ADS-B or TIS-B. The interval management function itself is then used to adjust the spacing such that after the S-curve the RPAT aircraft is parallel or slightly behind the target aircraft. Besides the basic concept and the technologies used, results from flight trials will be reported.

Keywords-Interval management, 4D, RNP, RPAT, pair approaches, closey spaced runways, GBAS

I. INTRODUCTION

In IMC, a closely spaced parallel runway system is still suffering from a dramatic decrease in arrival capacity. A lot of research has been carried out to address this problem. Required Navigation Performance seems to be one key enabler for parallel approaches in IMC. In the past, MITRE has proposed the RPAT concept (RNP Parallel Approach Transition) [1], in which one aircraft flies the usual straight-in ILS approach, which is bound by a normal operating zone (NOZ). The other aircraft (with respective RNP capabilities) flies an offset approach maintaining Instrument Flight Rules (IFR) separation. After the Final Approach Fix (FAF) the RNP aircraft initiates a guided S-turn to line up with the runway centerline. Before doing so, both aircraft need to be free of clouds so that separation can be maintained visually. However, the RNP aircraft will still be flown by the FMS until the wings are level. By the use of visual flight rules for the final approach the RPAT procedure is designed to be applied to runways spaced as close as 750 feet. Currently, RPAT operations require still relatively high weather minima (2000 feet and 4 miles).

Figure 1. Paired approach to SFO in VMC

ADS-B technology together with airborne spacing capability can be used to overcome these limitations. Instead of visual separation, the RPAT aircraft will then use airborne spacing functions to stay slightly behind the "Standard ILS aircraft" to avoid wake vortex encounter when established after the S-curve on the extended centerline. In addition, more stringent RNP capabilities might be required to fly the S-curve in IMC with visibility down to CAT I. Here, GBAS might be able to provide highly accurate positioning service with the required integrity for the FMS or even to provide the required information for a precision curved approach.

A. *Benefit estimation*

The following table (Table 1) gives a rough indication how the proposed concept can increase runway throughput of a closely spaced parallel runway system in IMC. It shows the runway throughput that can be achieved if paired approaches can be applied in an optimal manner, meaning that always a pair of a/c is approaching the runway system using an inner pair spacing of e.g. 5, 10, 15 or 20 seconds. If a normal landing rate would be 30 landings (no departure considered) the landing rate could be increased to 53 if an inner spacing of 15 seconds is used, given that the same spacing of 120 seconds between a pair of aircraft can be applied as between two aircraft in the base line assumption. Table 1 shows such consideration for different inner pair spacing intervals (5, 10, 15, and 20 seconds) and different initial landing rates (30 up to 40 landings per hour). Obviously, the smaller the inner pair spacing is the higher the maximum landing rate would be. Further on, the smaller the base line rate is the higher would the benefit be in applying the paired approaches concept.

TABLE 1. ROUGH BENEFIT ESTIMATION OF PAIRED APPROACHES ONTO CLOSELY SPACED PARALLEL RUNWAYS. NEW LANDING RATE IS GIVEN BASED ON BASELINE LANDING RATE (DEPENDENT RUNWAY SYSTEM) AND INNER PAIR SPACING INTERVAL

Landing rate in IMC Baseline (aircraft per hour)	Landing Rate using paired approaches			
	Inner Interval Spacing (in Seconds)			
	5	10	15	20
30	57	55	53	51
32	61	58	56	54
34	64	62	59	57
36	68	65	62	60
38	72	68	65	62
40	75	72	68	65

The basic concept has already been introduced in [1]. The following section will give a brief overview of the concept elements and the used airborne functions. The main focus in this work will be on the flight trials that have been conducted with DLR's ATTAS research aircraft using either a Beechcraft Be350 or DLR's A320 research aircraft ATRA as target aircraft. Since Ground based Augmentation System (GBAS) curved approaches might serve as an enabler to fly such paired approaches even under CAT I conditions, the final section will elaborate on how the GBAS Terminal Area Path (TAP) functionality can be used for implemented precision curved approaches.

II. BASIC CONCEPT ELEMENTS

Figure 2 and Figure 3 show the basic RPAT concept described in [2] and the enhanced concept to be applied in low visibility conditions, respectively. Two main modifications are proposed. The first concerns the traffic synchronization between the two aircraft. In the original RPAT concept, this synchronization is the task of the controller. He has to ensure that both aircraft fly in parallel until the RNP-aircraft starts its initial turn. A longer straight-in final for the ILS-aircraft and the aircraft on the parallel approach transition might be required to achieve the appropriate spacing at touch-down. In the proposed concept, this traffic synchronization is done via ASAS spacing (airborne/flight interval management). Of course, either the ILS-aircraft is equipped with ADS-B out or the required information for the spacing is provided via TIS-B where the TIS-B service is fed with data from a wide area multi- lateration system or by Precision Approach Radar

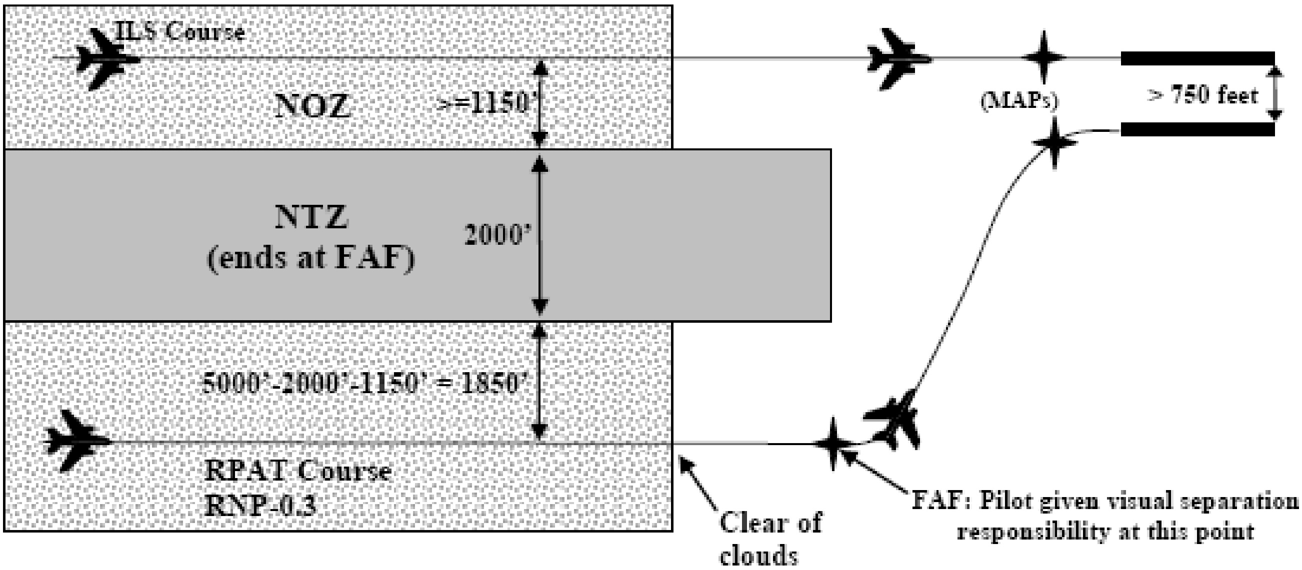

Figure 2. Diagram of basic RPAT procedure concept [1] (Not to scale)

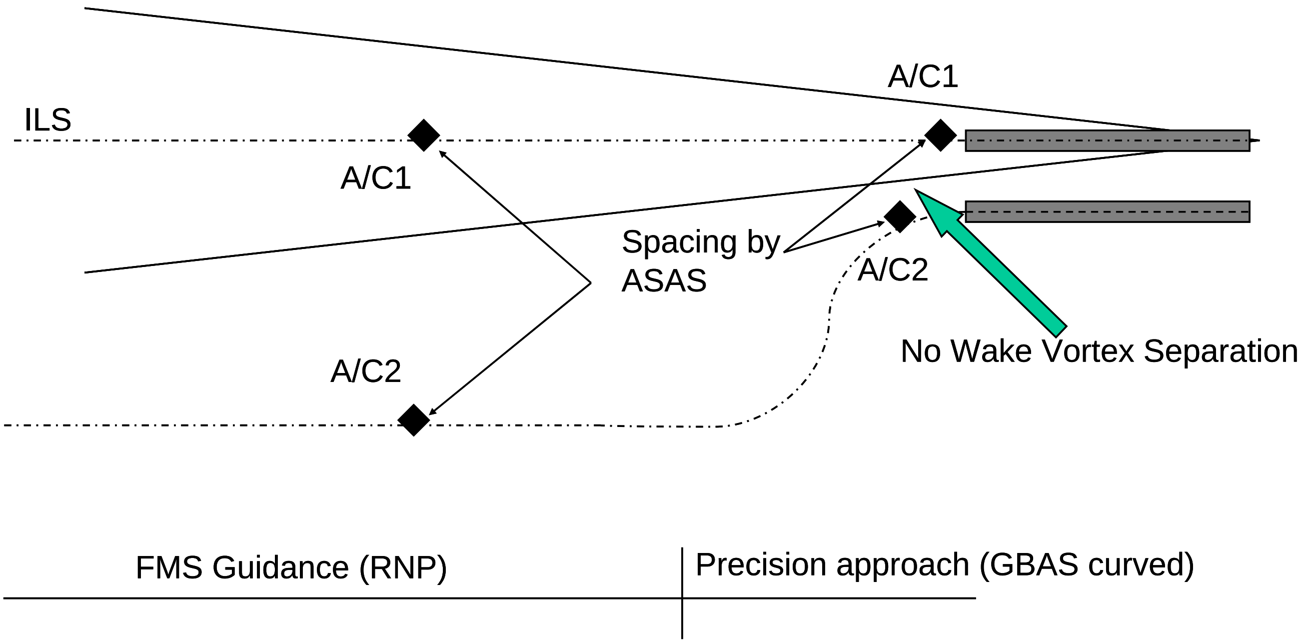

Figure 3. Enhancement of the RPAT concept to be applied in low visibility conditions

Being on an independent parallel track, the ASAS-aircraft can fly its own speed profile. It has to predict the trajectory of the ILS aircraft and can then adapt its target time when the turn on final should be finished to arrive shortly after the ILS aircraft at the threshold of the closely spaced parallel runway.

Secondly, since no visual contact with the "ILS-aircraft" is required, the S-curve part of the final approach is flown under precision guidance ensuring that no overshoot will take place when turning on the last straight-in segment. Here, we propose a GBAS curved approach to precisely guide the aircraft through that final curve.

Obviously, the airspace structure – especially the approach procedures (the approach transitions) need to be designed to support this kind of concept most effectively.

B. Procedure Design

The task of the lateral path of the approach procedure is to ease the proposed approach concept. Since trajectory prediction and some combination of relative 4D navigation and ASAS guidance is foreseen, the procedure should allow for an initial adaption of the required trajectory by the ASAS aircraft. Further on, finer adjustments before the end of the S-curve should be possible, since no exact trajectory prediction of the ILS aircraft's trajectory can be expected. Based on this, as well the transition of the ILS aircraft should be based on RNAV and no or only a very limited amount of vectoring should be allowed to increase the accuracy of the trajectory prediction.

Figure 4 shows how procedure design can support the concept. The ILS aircraft should fly a standard RNAV transition to ILS intercept, followed by a standard straight-in final with G/S intercept at for example 3000ft or above. For the ASAS aircraft, as well an RNAV transition will guide the aircraft onto the parallel track. However, this transition contains a path stretching area which allows the aircraft to shorten or lengthen its lateral path and thus to make an initial adaptation of its time of arrival at the end of the S-curve. The distance after the path stretching area is long enough to do adjustments of the arrival time by speed modifications in the area of up to 10 seconds (depending on aircraft performance).

This kind of lateral path design already has been used successfully in DLR's FAGI project in which a time based separation at a late-merging point has been realized and as well proven in flight tests [3][4][5].

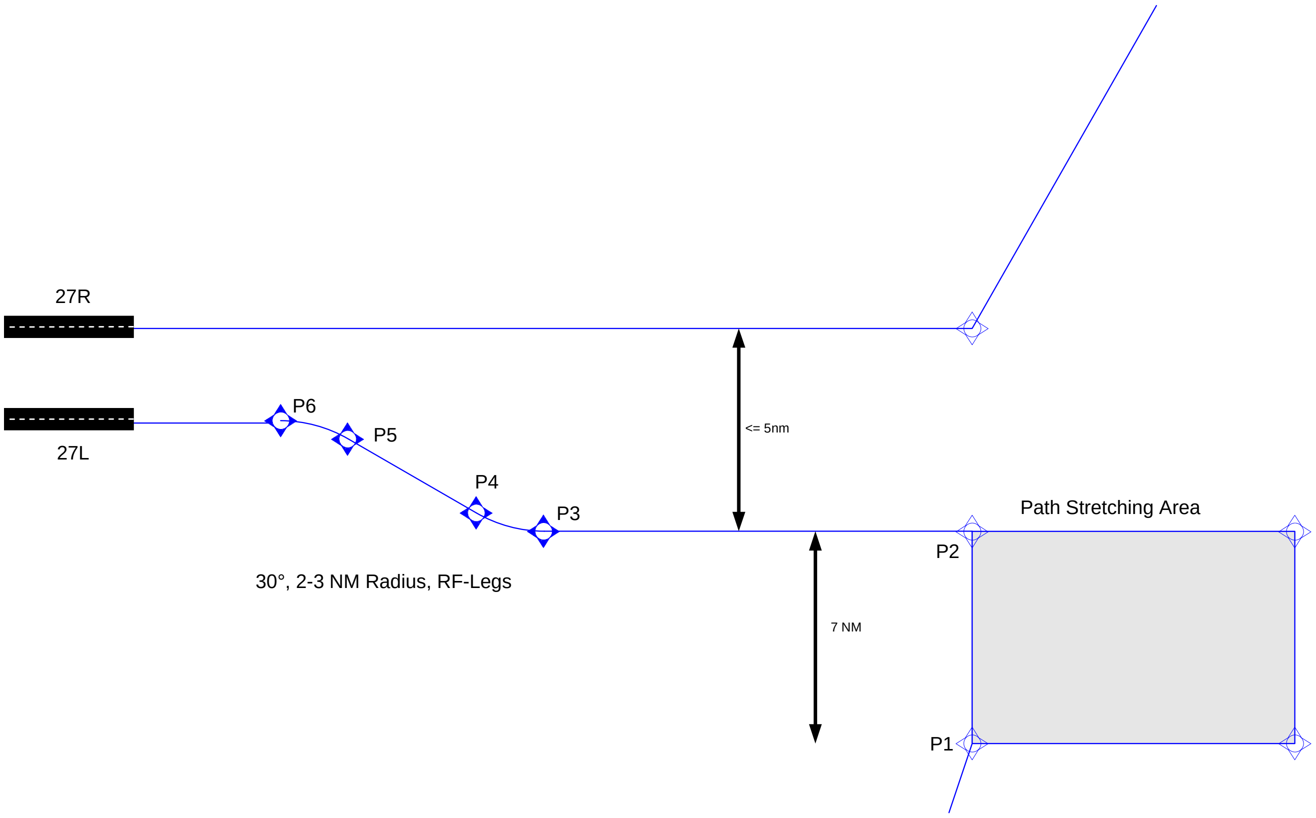

Figure 4. Procedure design for the enhanced RPAT concept

C. *Spacing concept*

The spacing tasks can be divided into two subtasks: the guidance part and the monitoring part. The monitoring part has to monitor the flight progress of both, the target aircraft (the ILS-aircraft) and of the ASAS aircraft on the parallel approach track. Deviations of both aircraft from their predicted path (in 4D) need to be detected and fed into the guidance appropriately. The guidance has to overcome these deviations and has to deliver the ASAS aircraft on-time at the roll out of the turn onto final such that it will be slightly behind the other aircraft. Here, the distance in time needs to be small enough to avoid any possibility of a wake vortex encounter and to be big enough not to interfere with the ILS-aircraft. For our trails we decided to use a 10 seconds spacing. As indicated above, this control task is divided into to phases. Before reaching the path stretching area at point P1 (see Figure 4), this area can be used to adapt the lateral path. This gives the FMS the possibility to calculate a 4D reference trajectory with an RTA at P5. This RTA is calculated as 10 seconds later after the ETA of the ILS aircraft at that respective point on its trajectory. Consequently, the standard 4D guidance of the FMS is used until the aircraft will leave the path stretching area at P2. After this point, a more direct control of the trajectory will take place. Based on the permanent update of the predicted trajectory of the ILS aircraft, the own speed profile needs to be updated. From an onboard perspective deviations of the current ETA from previous ETAs can be treated as “normal” deviations in the own 4D guidance. Thus, a modified ETA would result in a similar behavior of the guidance as measured deviations in the actual wind as compared to the wind forecast [6]. Another possible solution would be a more direct ASAS spacing function which uses a combination of the current position of the ILS aircraft and its predicted ETA at the projection of P5 onto the ILS path [7].

It is not really required that the spacing, the trajectory predicting and the guidance will be performed by airborne functions. In the FAGI project [3], respective support functions have been developed to handle a mix of 4D and not 4D capable aircraft in a late merging point concept. A combination of ghosting, and speed and turn advisories has been successfully tested to achieve a time based spacing at the merging point [3]. However, in this paper we will elaborate an airborne solution in more detail.

III. AIRBORNE FUNCTIONS

As states above an airborne based realization of the described concept requires the following airborne functions: a high navigation performance including a precision curved approach, a 4D capability to plan and execute a trajectory with a RTA at the end of turn onto the final and an ASAS spacing function. As input for the 4D function and the ASAS function a trajectory prediction module is required that generates an ETA for the target aircraft at the point of interest based on ADS-B data. Since a precise 4D guidance requires a high navigation performance the path until the FAF of the curved approach should be flown using RNP performance (with RNP value < 0.3). Basically, the concept foresees an automated execution of the entire approach. However, appropriate information should be given to the pilot with respect of system performance for both, the navigation performance and the separation/spacing situation as e.g. investigated in [8][9].

For demonstrating the feasibility of the proposed concept, all required airborne functions have been developed and integrated with our experimental FMS, the Advanced Flight Management system, and its respective human machine interface, a modified navigation display.

The Advanced Flight Management System (AFMS) is being developed based on the Experimental FMS developed within the Programme for Harmonized Air traffic management Research in EUROCONTROL (PHARE) [12][13][14].

The conventional Flight Management functionality is extended by co-operative elements, which connect traffic planning modules on the ground to flight planning systems on board the aircraft via data link. The main features of the AFMS are:

- Computation of 4D-trajectories on board considering
- constraints received via data link from ATC,
- aircraft performance parameters,
- meteorological conditions
- economical criteria, etc.
- negotiation of the flight plan with ATC/ATM by means of data link connection, and
- 4D-guidance capabilities along the engaged negotiated trajectory.
- interactive navigation display as human machine interface
- FLS (FMS based Landing System) approaches including noise abatement approach procedures like Low Drag Low Power or (Advanced) Continuous Descent Approaches.

Additionally, the AFMS provides a Human Machine Interface (HMI) for the pilots. An example of this interface is given in Figure 5.

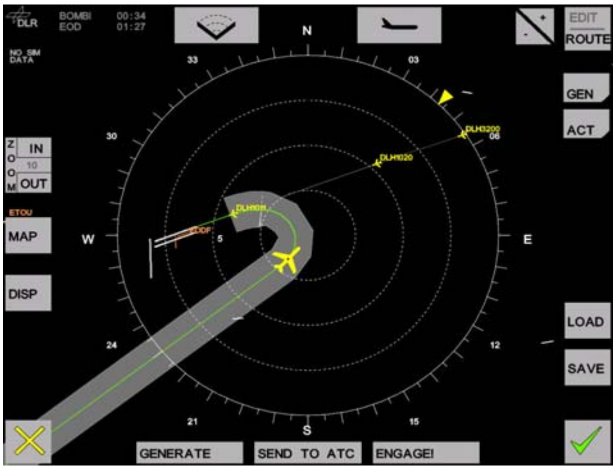

Figure 5. Navigation Display for AFMS

As an input for using the 4D capability of the AFMS, a trajectory prediction of the target aircraft (the ILS aircraft) needs to be done. The Trajectory Prediction (TP) is based on the Advanced Flight Management System (AFMS). It uses aircraft data and ADS-B messages to predict a flight path and calculate an estimated time of arrival (ETA).

Knowledge of the aircraft model and the intended flight plan (destination airport, cruise altitude, passed waypoints) as well as reception of sufficient flight data via ADS-B is needed for the prediction of the flight path and the calculation of the ETA. Mandatory ADS-B content for a successful prediction is the lateral position of the aircraft (given in latitude and longitude) as well as the pressure altitude. Heading and ground speed are used if available, but can be reconstructed if at least two ADS-B messages have been received.

The first prediction uses the AFMS to create a trajectory from the current position down to the runway threshold of the destination airport. By that the ETA can be calculated for any requested position on the flight path, e.g. arrival at the final approach fix (FAF) or at the runway threshold (touchdown). Aircraft weights (zero fuel weight, fuel weight) are needed for that step of prediction and will be estimated if they are not known by other means. Weather forecast may or may not be included.

The lateral profile of that first predicted trajectory is then used as a prototype for further prediction. Re-planning of the route takes place if the lateral offset, calculated with every new reception of ADS-B messages, gets too large. Otherwise differences of predicted speed and actual speed are used to update the ETA.

A. Relative spacing via 4D

As described above the relative spacing is designed as a two-step approach. In the first step, based on the initial predicted trajectory of the target aircraft, a new RTA for P5 is set and a new reference trajectory will be generated taking into account the possibility of doing path stretching by modifying the lateral position of P1 and P2 respectively. The size of the path stretching area defines the interval in which the RTA can be achieved at point P5. Whereas an additional delay can be realized easily (just make the path as long as required) there is of course a natural limit for gaining time. In

Figure 6 the shortest possible path is depicted on the onboard Navigation Display. Here P2 is moved in such a way that it will end up at the same position as point P3. Compared to the initial positions of P1 and P2, the time of arrival could be shifted approximately 160 seconds earlier. This should give enough flexibility to adapt the own trajectory to the predicted trajectory of the target aircraft.

After the initial trajectory has been generated and activated, adaptations of the RTA with respect to a new ETA of the target aircraft can only be achieved via speed adjustments. In our experiments we used our standard 4D guidance of the AFMS to compensate for new ETAs of the target aircraft coming out of the TP-module. The difference between the new ETA and the old ETA is simply fed as an additional deviation into the guidance process.

Figure 6. Standard route via initial settings of P 1 and P2 and shortest possible way using the path stretching area as depicted on the Navigation Display

The effect can be seen in Figure 7. Here, directly after the aircraft passes point P2, an extra deviation of 10 seconds has been introduced in the guidance process representing a new ETA which was 10 seconds earlier than the previous one.

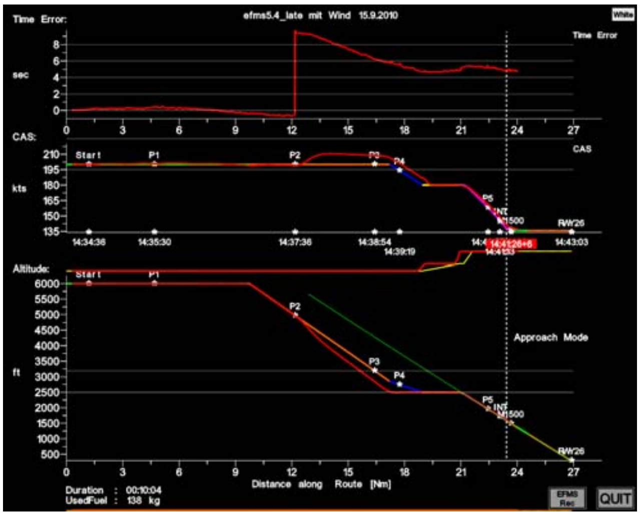

Figure 7. Behavior of the guidance module if an additional deviation of 10 seconds is introduced representing an ETA of the target aircraft which is 10 seconds earlier than the previous one

This extra deviation can be seen by the peak in the time deviation part in the upper area of this diagram. It can be seen as well how the speed profile is modified by the guidance to compensate this extra deviation. In the end in this example, 5 seconds still remain at P5. The same amount of error occurs if a 10seconds later ETA is introduced in the guidance process at P2. This shows that there is still some work to be done in modifying the guidance process to reach the envisaged 10 seconds target. E. g. the guidance could use as well speed modifications on the level segment slightly before reaching P5.

B. Display of Wake Vortex in Navigation Display

For increased situation awareness of the flight crew a depiction of the wake vortex of the target aircraft has been added to the navigation display (see Figure 8). It shows the area behind the target aircraft that must not be entered.

The calculation of this hazard zone is based on DLR's research being done in the project "Weather and Flying" [15]. It combines the wake vortex prediction model P2P [16] and the Simplified Hazard area prediction (SHAPe) method [17]. P2P takes into account effects of aircraft configuration, wind, wind shear, turbulence, stratification and ground proximity. SHAPe quantifies the severity of a potential wake encounter. In relation to nominal wake vortex positions, areas are determined outside of which no hazard due to wakes exists, i.e. where flight operations can be considered as safe and undisturbed.

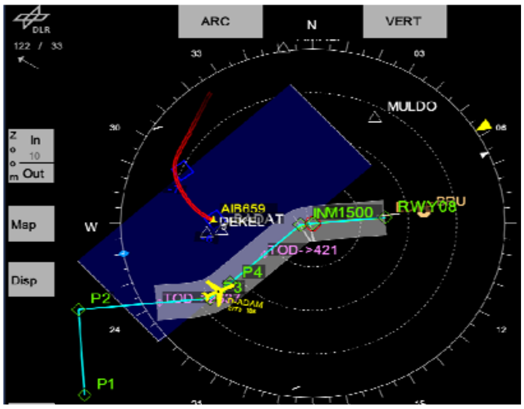

Figure 8. Dipiction (in red) of wake vortex of target aircraft in Navigation Display

IV. Results of Flight Trials

The flight trials have been performed using DLR's ATTAS aircraft (see Figure 9), which is equipped with an experimental fly-by-wire system enabling easy access to all control surfaces. In addition, it is equipped with DLR's 4D-FMS. This FMS is able to calculate a trajectory with time constraints. In addition the FMS can provide the guidance information to an experimental autopilot developed by the DLR's Institute of Flight Guidance. This autopilot is able to fully control the aircraft and its engines.

For the flight trials, the most important time constraint was the one for the merge point (M1500) of the two procedures. This time constraint is dependent on the trajectory prediction of the leading aircraft. This prediction is based on the received ADS-B data. For the flight trials with the Beechcraft 350, the ADS-B data was received via a S-Band data link in a TIS-B fashion. The reception of the ADS-B data was very well throughout the trials.

Figure 9. DLR's test aircraft VFW 614 ATTAS

A predefined offset was added to the predicted ETA to ensure wake vortex separation. The goal was to have an actual time difference of 10s +/- 5s at the merge point. Some results of flight tests with the Beechcraft 350 are shown here. Usually, four to six approaches were conducted during a single trial. Results for some approaches are shown in Table 2. Only results from the flight trials with the Be350 are shown in the table as more approaches were conducted with this aircraft and there were some issues with the ADS-B reception during the trials with the ATRA.

The first column of the table shows the runway direction used for the approach. The second column shows the predefined offset in the time constraint of the 4D FMS. This offset could be adapted manually to be able to adapt the functionality during the trials and provide some flexibility in case of unexpected results. The third column shows the actual time difference of the two aircraft during the trials. It can be seen that the predefined offset could be kept in most of the times.

Table 2: Flight test results (Be350)

RWY used	Δ time (setup)	Δ time (actual)
26	8	4
26	12	6
08	10	14
08	10	14
08	5	9
08	2	8
26	10	1
26	10	9
26	5	3
26	6	3
26	8	8
26	8	9
26	6	4
26	13	20
26	6	8
26	6	6
26	6	10

It can be seen that the ATTAS with its 4D-FMS was able to maintain the time separation that was preset before conducting the procedure with a high degree of precision. In addition, it never occurred that the trailing aircraft arrived before the leading aircraft which could be an issue for the leading aircraft depending on the wake vortex class of the two aircraft. The results of the flight trials presented in the table above show that even if the leading aircraft is flown manually the 4D-FMS of the trailing aircraft can provide guidance to the merge point with an accuracy of +/- 5s in the majority of the cases.

During the trials with the ATRA as leading aircraft, some issues with the ADS-B reception on board of the ATTAS occurred. For these trials an ADS-B receiver was integrated into the ATTAS in order to receive the ADS-B data of the leading aircraft directly. The receiver was integrated into the cabin as experimental equipment and an experimental antenna in the back of the fuselage was used, the antenna and the connection to the receiver was not optimal and due to the antenna position some shadowing effects occurred.

Therefore, the ETA of the ATRA could not always be calculated due to the lack of data. Due to that, the ATTAS was adapting its flight path to the initial prediction. If the change in the prediction was too big after the ADS-B data was received again,, the difference could not be compensated for with airspeed only. That was the main reason why the ATTAS usually arrived too late at the merge point in the trials. An example of that behavior in given here: The ATRA (leading aircraft) arrived 15s earlier at the merge point than initially predicted. As the ATTAS (trailing aircraft) was supposed to arrive 10s after the ATRA but it actually arrived 24s later than the ATRA.

It can be seen that in this case the ATRA was well early at the merge point and therefore, the ATTAS was not able to stay inside the target time window. This is an issue especially if the initial turn of the experimental procedure is already over. As the allowable airspeed margin is rather small due to the required configuration of the aircraft (flaps, gear), huge adaptions cannot be compensated easily solely based on change in airspeed. Taking all approaches into account, there was a success rate of 60%.

The shadowing effect of the antenna during the trials with the ATRA was worst during the initiation of the procedure as it was facing away from the ATRA. During the Be350 trials with the transmission of the ADS-B signals via a proprietary DLR S-Band data link (in a TIS-B like fashion) the reception was better and the success rate significantly higher as seen in Table 2.

The trials show that the prediction of the trajectory of the leading aircraft is crucial for the execution of the proposed procedure. Therefore, it can be stated that a precise position broadcasted via ADS-B is very helpful in terms of trajectory prediction. One foundation for a good prediction is a broadcast of a highly precise position. This can be achieved through GNSS augmentation systems like SBAS or GBAS. Additionally, a high update rate (i.e., more than the typical rate of 1Hz or 2Hz) of the ADS-B transmission could assist in enhancing the prediction.

If the two trials (one with ATRA, one with the Be350) are compared, it must be taken into account that the Be350 is flown manually based on the position information provided to the crew by a DGPS installation. The standard approach procedure was loaded from the navigation database of the aircraft. Additionally, a speed profile for the different segments of the procedure was provided to the crew. The trials showed that the crew was able to maintain the flight path in space and time and very good results with the time constraints at the merge point could be observed. It can be seen that the less precise guidance of the Be350 can be compensated for by the 4D-FMS on board the trailing aircraft. As the speed range of the Be350 is rather small during the approach, large speed deviations were not observed and are rather improbable. It seems probable that a 4D-FMS of a generic trailing aircraft would have to be adapted to the allowed speed profile of the leading aircraft.

As stated, it was also observed during the flight trials with ATRA and ATTAS that the ADS-B reception of the signals transmitted by the ATRA was degraded with large distances between the two aircraft. Due to that, the ETA could not always be calculated properly. This is also a reason why better results were obtained during the trials with the Be350. A steady reception of ADS-B signals is necessary to calculate a reliable prediction. Therefore, the ground based transmission of TIS-B in the vicinity of an airport where the presented procedure is to be implemented seems favorable.

V. USING GBAS TAPS TO FLY PRECISION CURVED APPROACHES

Flying this paired approach not only under visual conditions but even under CAT I conditions will require precision guidance on the final but still curved segment. GBAS can provide such guidance using the Terminal Area Path (TAP) functionality. However, current avionics is not capable of flying a precision curved approach automatically; the autopilot system would interpret the deviations delivered by the MMR (Multi-Mode-Receiver) as deviation to a straight-in approach. A solution could be the use of a head-up display (HUD) in combination with a tunnel guidance concept. Using tunnel guidance on a HUD, a highly precise guidance with a sufficient small flight technical error of the pilot could be achieved [10]. The tunnel guidance can as well be combined with ASAS functions as described in [11]. A path design with TAP waypoints is given in Figure 10.

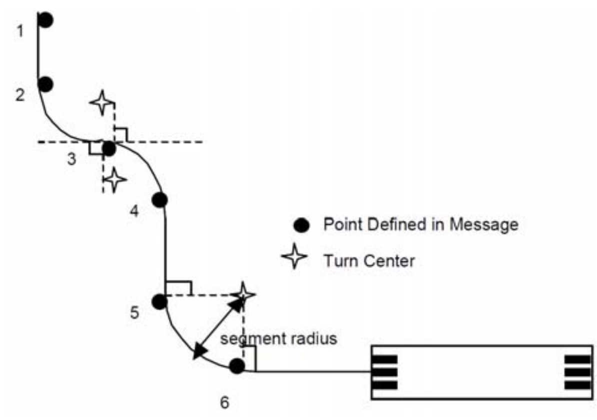

Figure 10. Curved Approach as TAP from [18]

Straight segments (Track-To-Fix) and curved segments (Radius-To-Fix) are used to design a curved approach procedure. This reference flight path is broadcasted by the GBAS ground station. In addition, the ground station provides the position accuracy and the integrity for a CAT I approach. As stated, current avionics systems would have to be adapted to use this functionality.

With that fact in mind, some simulator trials were carried out in order to investigate a method to use the TAP functionality with minimal need of adaption of current systems (see also [19]). The simulator used was the Generic Experimental Cockpit (GECO) of DLR's institute of Flight Guidance. A simulated MMR is integrated into the GECO. In addition, the simulator is equipped with an experimental autopilot, being representative of current installations. In order to keep the current installation, it was investigated how precisely the flight path can be maintained during curved approaches using only lateral and vertical deviations and the runway direction.

The deviations were calculated during the straight and the curved segments. In addition, the virtual runway direction was calculated during each segment. During straight segments the virtual runway was the true track between two waypoints. During curved legs it was the tangent of the position projected onto the curve. Therefore, the runway direction changed during the curved leg.

These three parameters are already transmitted in current MMR and autopilot/FMS installations. Therefore the adaptions required would only affect the software of the MMR. With this setup, different curved approaches were flown automatically.

Within a TAP, the sensitivity with which the angular deviations are calculated can be adapted in every segment of a TAP. Figure 11 shows the observed lateral deviations during a TAP with different sensitivities.

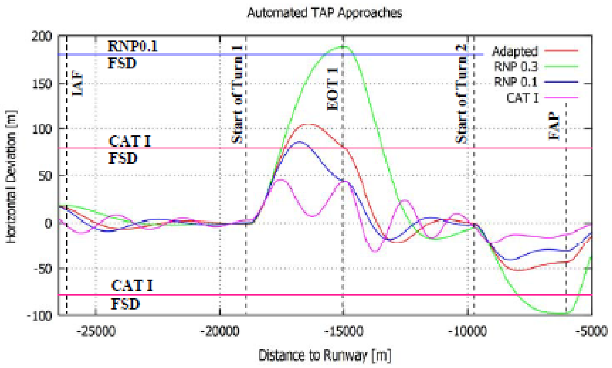

Figure 11: Observed lateral deviations

It can be seen that with a proper sensitivity value, the required flight path following accuracies for approaches in CAT I conditions can be achieved. The horizontal lines represent the Full Scale Deflection (FSD) for a given accuracy requirement. The vertical lines represent the borders of the individual legs of a TAP.

The same is valid for the vertical accuracies as shown in Figure 12. Another observed effect there, is the instability of the vertical flight path if the sensitivity is too great. Therefore, a result of the trials is the insight that the sensitivity would have to be adapted individually for each leg to get the required path following accuracies.

The trials were conducted using two different TAPs and the accuracy is to a certain degree dependent on the TAP design. If the track angle change of the curved leg is too great (approx. 60°), the accuracies for CAT I cannot be met. For the approach path considered during the paired approaches presented in this work however, the observed accuracies are sufficient. To be able to acquire the required accuracies independently of the approach path, the MMR and autopilot setup would have to be adapted heavily.

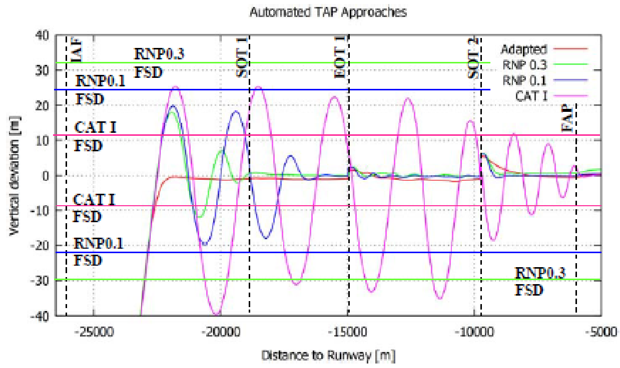

Figure 12: Observed vertical deviations

VI. Conclusion and Future Work

In this paper we have described an enhancement of the well-known RPAT approach concept to closely spaced parallel runways. With the presented concept, RPAT could also be conducted during low visibility conditions. The concept is based on a precision curved approach that can be aided by a GBAS in order to assure accuracy and integrity as well as ASAS spacing based on ADS-B data reception. Adequate approach procedure design items as well as the required onboard functions on the trailing aircraft have been presented. It was shown that an adaption of the ADS-B data broadcast rate and a reliable reception of those signals is viable for the presented concept. A lack of data results in a poor prediction of the arrival time at the merge point. This could lead to an increased number of go-arounds or controller workload.

In addition, another result of the flight trials was that the transmission of the ETA of the leading aircraft (if equipped also with a 4D-FMS) would enhance the path and airspeed adaption of the trailing aircraft. Feasibility of the concept has been demonstrated via experimental flight trails with different aircraft and current avionics equipment.

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