FLIGHT TESTING OF AUTOMATED CLOSELY SPACED PARALLEL APPROACHES

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Abstract

As the international air traffic increases and becomes more and more complex there is a growing demand for new operational procedures. Especially the runway capacity is a limiting factor for the maximum number of flights that can be conducted on an airport. Airports with a dependent parallel runway system cannot exploit the full potential of the individual capacity of a single runway as approaching aircraft have to maintain an increased separation due to the threat of wake vortices.

1. INTRODUCTION

In this work an automated approach procedure was flight tested. The procedure aims to increase the capacity of a dependent parallel runway system. Two parallel runways are considered dependent for simultaneous arrival operations if their distance is less than 1035m and their thresholds are aligned (see [1] and [2]). Based on the visual procedure used at San Francisco airport (KSFO) one aircraft (the “leading” aircraft) is flying a standard approach procedure (i.e., RNAV or ILS) with certain time constraints while a second aircraft (the “trailing” aircraft) is flying a parallel approach that leads to a merge point at which the two aircraft are flying nearly parallel with a separation between 5s and 15s.

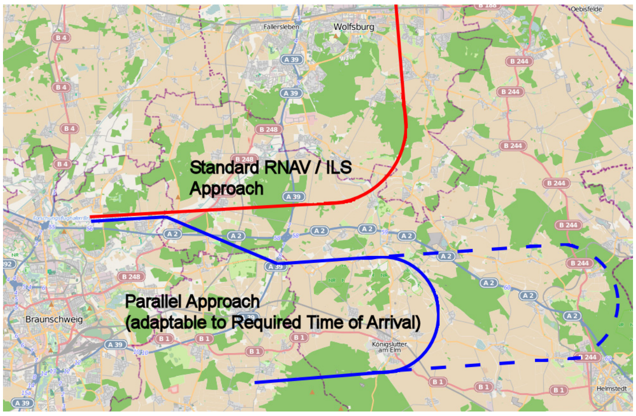

FIG 1. Proposed Approach Procedure

Several flight trials have been conducted at the Braunschweig-Wolfsburg airport. They required a detailed planning and briefing and had initially high demands on the equipment of the participating aircraft. The trajectories during the trials had to be coordinated between the two aircraft and with Air Traffic Control (ATC). In this paper the methodology used to finally conduct flight trials with two real aircraft as well as the equipment used is shown.

After simulations and trials with only one real aircraft (the leading aircraft was simulated in this case), different real leading aircraft were used (King Air 350, Airbus A320). The trailing aircraft, the Advanced Technologies Testing Aircraft System (ATTAS, VFW 614), equipped with the in-house developed 4D-FMS and autopilot, conducted approaches onto a simulated parallel runway (see FIG 1).

As the airport offers only one runway, an artificial ILS onto a parallel taxiway had to be created. The paper describes the different stages of the technical installations of the aircraft and presents the design, the buildup approach and the results of the conducted flight tests.

2. INFRASTRUCTURE AND METHODS

The key enabler of this procedure designed for wake turbulence mitigation for arrivals (WTMA) as described in [3] is a 4D-Flight Management System (FMS). This FMS allows the guidance of an aircraft in space as well as a precise guidance in the time domain. This experimental FMS was integrated into the ATTAS, a flying test bed used by the German Aerospace Centre e.V. (DLR). With this FMS, the proposed simultaneous approach procedure was flight tested. In total three different aircraft were used during the trials (two different leading aircraft and the ATTAS as trailing aircraft). The verification of the procedure was done in several steps, starting with different simulations, flight trials with a single aircraft and ending with flight trials with two aircraft conducting actual simultaneous approaches.

2.1. Experimental Setup of Aircraft

In this section, the setup of the different aircraft used will be described as well as the design of the approach procedure. In addition the flight test techniques will be shown.

2.1.1. ATTAS Equipment

The Advanced Technologies Testing Aircraft (ATTAS) was used by DLR for 26 years for many flight trials. It was equipped with an experimental fly by wire system that was fully accessible by the integrated experimental equipment. A 4D-FMS and an experimental autopilot (developed by the DLR’s Institute of Flight Guidance) were used in the ATTAS. The 4D-FMS (see chapter 2.1.1.1) is able to provide precise guidance in the space and the time domain. The position sensors used include VOR, DME, ADF, INS and DGPS as well as precision landing aids, like an ILS. The DGPS used was an OmniSTAR system. This DGPS is coupled with INS data taken from the aircraft thus providing highly precise position information with high integrity.

In addition, to be able to receive the ADS-B data of the leading aircraft, at a first stage an ADS-B receiver was installed on the ground and the received data was transmitted to the ATTAS via a S-Band data link. During a second stage of the trials, an ADS-B / TIS-B receiver was installed in the ATTAS and the received data was used to conduct the trials.

2.1.1.1. 4D-FMS

The 4D-FMS was developed at DLR within the project Programme for Harmonised ATM Research in EUROCONTROL (PHARE). The 4D-FMS has been enhanced continuously by DLR by including many improvements and new applications.

The purpose of this FMS is to create a highly accurate 4D-trajectory and to guide the aircraft along this trajectory precisely timed. The input data necessary for the trajectory generation are:

- Aircraft state vector
- Meteorological data
- Aircraft performance data
- A constraint list (i.e., a waypoint list containing time and airspeed constraints)

The aircraft state vector is obtained from the aircraft sensor system and is used for the starting conditions of trajectory prediction as well as for monitoring trajectory deviations during flight. The meteorological data is read from a forecast file in GRID file format provided by the German weather forecast service (DWD). The forecast meteorological data is improved during flight by on board measured data. The aircraft performance data and models (engine model and aerodynamic model) have been evaluated and improved during several flight tests since 1993. The constraint list is sent by an Airborne Human Machine Interface (AHMI) when the pilot invokes a trajectory prediction. It describes the lateral route from a start point up to the touchdown point under consideration of altitude, speed and time constraints. In addition, a descent profile can be chosen: Low Drag Low Power (LDLP) or Continuous Descent Approach (CDA).

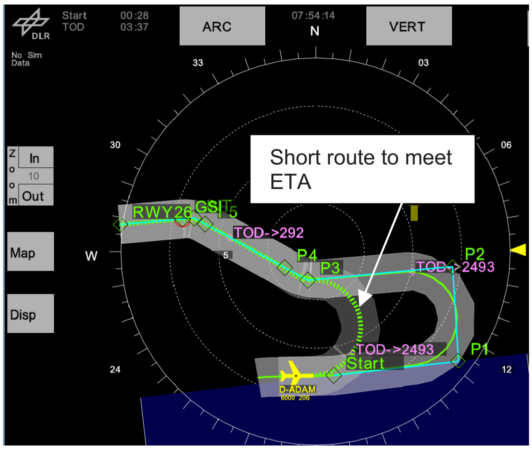

FIG 2. FMS Path Adaption

The lateral route consists of great circle legs between waypoints and arcs with a fixed radius at the waypoints. The vertical profile consists of a sequence of flight phases: climb, level flight, descent, combined with constant speed or acceleration or deceleration phases. The climb is predicted at high power setting. The descent is planned with idle power setting. The vertical profile is calculated by the integration of equations of motion over time. The vertical profile is calculated independently from the lateral path. This allows the calculation of curved approaches used for the closely spaced parallel approaches.

Airspeed and altitude profiles are planned and modified such that all altitude, speed and time constraints are fulfilled, whenever possible (see also [4]). If the maximum speed variation is not sufficient to reach a time constraint, path stretching can be used to extend or shorten the lateral route to adapt the arrival time (see FIG 2).

4D-FMS guidance module guides the aircraft along the predicted trajectory by calculating bank angle, calibrated airspeed and thrust demands to minimise the lateral and vertical deviations from the predicted trajectory.

2.1.1.2. ETA Prediction

Another component on board the ATTAS was DLR's traffic simulator (TrafficSim), which simulates the leading aircraft and its ADS-B data as described in [5]. Received ADS-B data of the leading aircraft are used to predict the Estimated Time of Arrival (ETA) of the leading aircraft at the merge point. In addition to the ADS-B data the wind predictions, the lateral and vertical profile to be flown by the leading aircraft (i.e., the standard routes) and optionally the performance data of the leading aircraft are taken into consideration.

Based on that ETA the trajectory of the ATRA was adapted either by varying the airspeed or a change of the flight path or a combination of both. If the ATTAS already started its initial turn, no adaption of the flight path was possible, therefore only a change of airspeed could be used to comply with the time constraint. For the adaption of the airspeed the current configuration of the trailing aircraft (flap position and gear position) has to be considered. Depending on the aircraft type the possible speed modifications are rather small. Therefore the flight path adaption was used as a coarse adjustment to the calculated ETA of the leading aircraft in the beginning of the procedure and the airspeed adaption was used to fine tune the required time of arrival at a later stage. The adaption of the airspeed was disengageable to be able to test the flight path adaption independently. As stated before, the aim is to align the trailing aircraft between 5s and 15s (depending on the wake vortex categories of the aircraft) behind the leading aircraft. This time offset was manually set to 10s but could be changed online during the trials.

2.1.1.3. Display Systems

A Primary Flight Display (PFD) and the AHMI was generated for the experimental pilot on board of the ATTAS. On the AHMI the own aircraft's position was displayed as well as the own planned route (see FIG 2 and FIG 3). Additionally, TCAS information as well as ADS-B traffic information is displayed on the AHMI. Another feature, integrated into the AHMI is the display of the wake vortex region of the leading aircraft. A corridor marked by red lines is shown on the AHMI to inform the pilot about the progression of the wake vortices generated by the leading aircraft (see FIG 3).

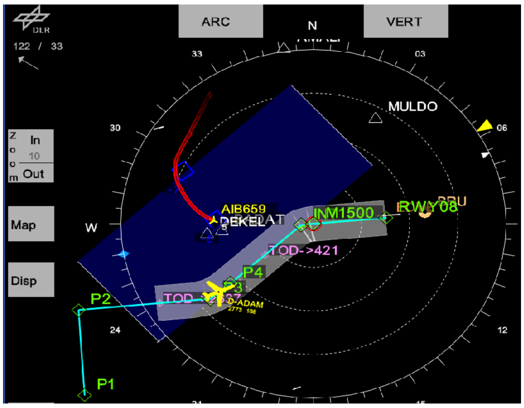

FIG 3. AHMI display (ATTAS)

The wake vortex region was calculated, as described in [6], based on a model developed by the DLR's institute of Flight Systems. In addition this region was briefed before each flight depending on the prevailing wind conditions on the given day.

2.1.2. ATRA Equipment

The Advanced Technologies Research Aircraft (ATRA) was also used in the flight trials. The ATRA was equipped with two racks with experimental equipment installed in the cabin. The experimental equipment consisted of the interface with the basic aircraft data, an operator station and the 4D-FMS. The 4D-FMS was adapted to the aerodynamic model of the A320 but provided the same functionality as the 4D-FMS used in the ATTAS.

The guidance calculated by the 4D-FMS was shown on an experimental cockpit display. This cockpit display is installed on the map table on the right hand side of the ATRA cockpit. The display can be stowed in the table slot. If it is unfolded the display is in front of the basic displays of the aircraft. Therefore, the standard instruments are generated by the experimental equipment and shown on the cockpit display. These standard instruments consist of a PFD, an engine and configuration display (e.g., flaps and gear) as well as the AHMI similar to the one used in the ATTAS.

The standard trajectory of the leading aircraft was flown manually by the pilot of the ATRA following the flight director commands generated by the 4D-FMS. In contrast to the original concept in which the leading aircraft does not necessarily has to have a 4D-FMS, the system was used here to precisely predict the ETA at the merge point and the compare that prediction with the prediction generated via the ADS-B data. This information was transmitted via VHF voice communication and only used later during data analysis. It was not used to update the ETA prediction online during the trials.

2.1.3. Be350 Equipment

For first flight trials using two real aircraft, the leading aircraft was a Hawker Beech Super King Air 350, operated by Flight Calibration Services (FCS) GmbH in Braunschweig.

This aircraft is equipped with a flight test instrumentation required for flight calibration services. For these flight trials the flight test instrumentation was only used for data recording. The crew of the King Air was instructed to follow the standard approach procedure (laterally and vertically) and additionally a fixed speed profile. The transmitted ADS-B data of this aircraft was used to calculate the ETA on board of the ATTAS and approach tests were conducted with this setup.

2.2. Setup of Flight Trials

Before actual flight trials were conducted, the experimental procedure with the path adaption functionality was tested in a simulation. Therefore, an artificial ETA was used in the simulation to test the path adaption functionality. The waypoints of the approach procedure were verified in the simulation as well. Without this verification real flight trials do not make any sense as a huge number of persons are involved in these trials. In addition, the procedures have to be coordinated with ATC as the flight path of the trailing aircraft is not a standard procedure. Once it was determined that the 4D-FMS provides the desired function a traffic simulator was used to simulate the leading aircraft and the transmission of the ADS-B data. In that way the path and speed adaption functionality could be tested in the simulation.

After the verification in the simulator was conducted successfully, first flight trials were conducted. In these first trials only the ATTAS was used. The leading aircraft was again simulated with a traffic simulator on board the ATTAS. The ATTAS was conducting approaches onto the virtual runway (i.e., the taxiway 'C' at Braunschweig-Wolfsburg airport) while the adaption to the ETA predicted via the simulated ADS-B data was taken into account. These approaches were only conduced in Visual Meteorological Conditions (VMC).

After this procedure was verified, flight trials with two aircraft were conducted. At this stage, the leading aircraft was a Be350, operated by FCS. After these trials were completed, the leading aircraft used was an Airbus A320 operated by the DLR. During the first two approaches with either of the two aircraft an additional height offset of 500ft was introduced to add additional vertical separation before the functionality of the involved systems was verified.

2.2.1. Standard Procedure

One aspect of this parallel approach procedure concept is that the leading aircraft does not require additional equipment or authorization. Therefore, the route for the leading aircraft is a standard route. It consists of a horizontal profile and different minimum altitudes.

For this investigation, the procedure started at an en-route waypoint in Flight Level (FL) 100. The next waypoint was another en-route waypoint followed by the Initial Approach Fix (IAF) for the standard RNAV procedure for Braunschweig-Wolfsburg airport. FIG 4 shows the pattern of the flight trails. The pattern in the north was the pattern of the leading aircraft which represents a standard arrival route.

The leading aircraft continued with an ILS approach once established on the extended runway centerline. The merge point was reached on the glide slope during the ILS approach. The procedure was flown completely under Instrument Flight Rules (IFR). The leading aircraft was controlled by ATC all the way.

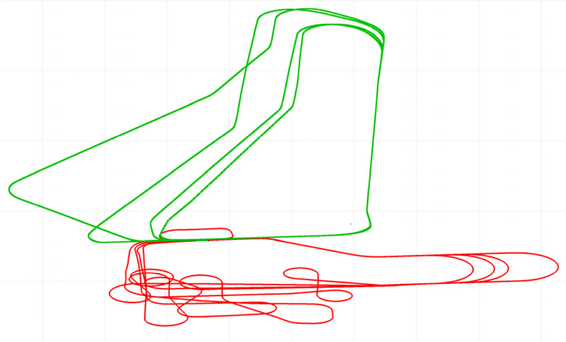

FIG 4. Sample Flight Test Patterns

The leading aircraft was conducting the standard procedure and initiated a go-around at the ILS decision height. After that, the leading aircraft was directed via radar vectors back to DIRBO by the air traffic controller.

2.2.2. Experimental Procedure

In contrast to the standard procedure for the leading aircraft the procedure for the trailing aircraft is fully experimental. It is based on different types of waypoints: Fly-Over and Fly-By waypoints as described above in the FMS description. These waypoints can be tagged with a time and airspeed constraint. The 4D-FMS will plan the trajectory according to these waypoints and the time constraints. Different factors (e.g. wind, maximum bank angle etc.) are considered.

To start the investigations regarding feasibility of flight trials to verify the proposed approach procedure, it was tested in a ground simulator of the DLR's Institute of Flight Guidance. As the flight path of the leading aircraft is a standard procedure for Braunschweig-Wolfsburg airport, no additional implementation was required. The procedure was already integrated within the simulation environment. The procedure for the trailing aircraft was then designed and integrated into the simulation environment. As the airport Braunschweig-Wolfsburg dos not have a parallel runway system, a virtual runway was assumed.

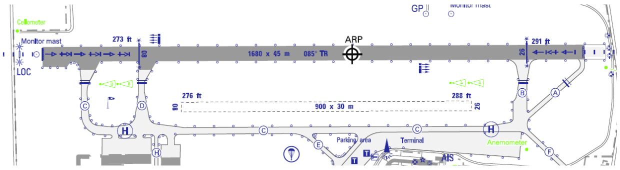

FIG 5. Aerodrome chart taken from [7]

The centerline of the virtual runway was aligned with the centerline of taxiway 'C' (see FIG 5). The threshold of the virtual runway was aligned with the real runway threshold of the concrete runway in the north. The taxiway was chosen as virtual runway as the distance between the taxi way and the runway is approx. 250m which represents the distance between two parallel runways in San Francisco (KSFO) where a similar procedure is used during visual flight using visual separation. In addition, the crew of the trailing aircraft had a visual reference if they were aligned on the synthetic ILS.

The same glide path angle of 3.5° was used for both runways in the direction 26. While the 3.5° glide path angle for the real runway was based on the existing ILS, the glide path of the ATTAS was computed on board based on the hybrid (DGPS and INS) position and different altitude sensors. A glide path angle of 3.0° was used for direction 08.

With this threshold point of the virtual runway and the glide path angle the experimental procedure was designed. The design was conducted from the threshold backwards so that the final segment is parallel to the last part of the final segment of the standard ILS approach of the real runway. Both flight paths remain parallel up to a merge point where both aircraft have an altitude of 1500ft above Mean Sea Level (MSL). At that point the experimental procedure has a track angle change of 30°. After a straight leg the procedure has another track angle change of 30° (see FIG 2).

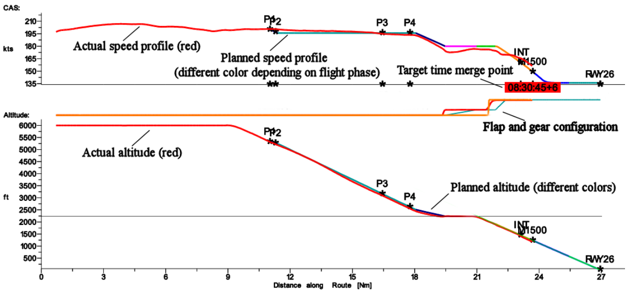

FIG 6. Vertical Profile and Speed Profile

The adjacent straight path was followed by a 180° turn and another straight segment ending at the starting point of the procedure. The position of the 180° turn could be adapted to the current estimation of the ETA of the leading aircraft at the merging point. FIG 6 shows the speed profile and the vertical profile of the experimental procedure. The red lined indicate the results from an actual flight test. The other lines represent the planned trajectory after the first initialization of the procedure.

If the ETA of the aircraft was earlier than it was when the procedure was initialized in the FMS, the path of the experimental procedure was shortened. If the ETA was delayed, the path was stretched so that the ETA could be realized with the ATTAS.

As the flight path for the trailing aircraft is neither fixed nor published, coordination with ATC during the real flight trials was important. As the trailing aircraft is already descending during the final turns of the procedure, IFR had to be cancelled for the ATTAS during every approach as it was flying below the minimum radar altitude at a certain point. The ATTAS had to continue visually after that. As visual contact with the leading aircraft was required for these trials anyway, VMC was maintained all the time.

2.3. Flight Test Methods

As stated above, the procedures were investigated in the simulator before any flight trials were conducted. This way the whole procedure was verified in a buildup approach. After extensive simulator trials were conducted, first flight trials were used to verify the procedure. The buildup approach concept was maintained here as well. First, the ATTAS was flying the experimental procedure without any other traffic to familiarize the pilots with the procedure. The experimental approach procedure was flown automatically. In this stage the pilots had to switch on the autopilot and to activate the trajectory calculated by the 4D-FMS. The time accuracy of the 4D-FMS used in the ATTAS was verified in previous trials (see [8] and [9]). It is able to guide the aircraft with a time error of approx. +/- 3s depending strongly on the accuracy of the wind prediction used. After the pilots were familiarized with the procedure and the operational crew procedures required, the leading aircraft (a Be350) was simulated by a traffic simulator (TrafficSim) on board of the ATTAS. In addition to the aircraft the wind prediction of the DWD was used in the TrafficSim as well. A description of the TrafficSim is given in [10]. In this setup the ETA adaption could be tested in the flight trials. Additionally, the display of the traffic on the cockpit display could be verified. In this stage the simulated leading aircraft was set up at different points along the standard procedure. Therefore, the flight time for the simulated aircraft was varied. In this way, the path stretching functionality of the 4D-FMS used in the ATTAS could be tested.

After these trials were conducted successfully, two aircraft were used for the first time. At first, a King Air was used as the leading aircraft. Before each flight, a briefing with all participating crews and scientists took place. In this briefing, the crew of the leading aircraft was briefed intensively with the standard routing of the procedure (horizontal and vertical) and additionally a speed profile was briefed which should be maintained by the leading aircraft. In contrast to the original idea, that the leading aircraft is only required to maintain the flight path in space to a certain degree (e. g. RNP0.1 and ILS on the final), this fixed speed profile was used to facilitate the ETA calculation in the ATTAS. In addition, for the first approaches an altitude offset of approx. 500ft was used. The QNH setting in the trailing aircraft was adapted so that it was flying higher than the leading aircraft to increase the separation.

The major risk during these procedures is an uncoordinated go-around maneuver. Therefore, the go-around procedure was briefed in detail before each flight. The leading aircraft was briefed to fly straight ahead or turn slightly to the north as the ATTAS was always flying behind and south of the leading aircraft independent of the runway direction used. The escape maneuver of the ATTAS was briefed to be a slight turn to the south trying to maintain visual contact with the leading aircraft. To be able to maintain visual contact throughout the trials, the minimum cloud base was required to be greater than 4000ft MSL. No flight trials were conducted during worse weather conditions.

In addition, the DLR company frequency was used to establish radio contact between the two aircraft. Therefore, one of the VHF radios of each aircraft was tuned to the company frequency and the other VHF radio was used to stay in contact with ATC. In that way, the pilots of the ATTAS could report if the visual contact was lost so that the leading aircraft would turn slightly to the north and would not climb excessively. Without visual contact the pilots still could use the ADS-B and TCAS display to avoid the traffic.

For the flight trials the ATTAS was circling over an area south of the airport. The orbit patterns used had a standard flying time of two minutes. The experimental pilot was monitoring the AHMI where the ADS-B information was displayed. Once the pilot saw the leading aircraft reached the starting point of the standard procedure the ATTAS was heading to the starting point of the experimental procedure (START, see FIG 2). At that moment the base trajectory for the trailing aircraft was activated and the ETA of the leading aircraft was calculated continuously. Radio contact with ATC as well as with the other aircraft was maintained by both aircraft during the trials. ATC also had to coordinate the trials with the normal traffic in the vicinity of the airport.

Up to the waypoint “START” (see FIG 2) of the trajectory before the initial 180° turn the trajectory of the experimental procedure was adapted to the ETA prediction generated on board of the ATTAS. The flight path was either shortened or extended. The path adaption allows a verification of the flight time for the experimental procedure up to +/- 3 minutes. After that point the ETA at the merge point was adapted only by changing the airspeed. At the end of the flight trials the leading aircraft was landing out of the last approach while the trailing aircraft conducted another go-around and landed after a short traffic pattern.

3. RESULTS

In this chapter, some results of flight tests with two real aircraft are shown. Usually, four to six approaches were conducted during a single trial. Results for different approaches are shown in TAB 1. In the first column the type of the leading aircraft is shown. The second column shows the runway direction used for the approach. The third column shows the difference between the Actual time of Arrival (ATA) and the ETA that was calculated by the prediction in the moment the procedure was initiated. The prediction was adapted continuously throughout the procedure. It can be seen that the different parameters that have to be taken into account (e.g., the wind prediction) were influencing the initial prediction so that differences up to values of 15s occurred.

During the trials with the ATRA as leading aircraft, some issues with the ADS-B reception on board of the ATTAS occurred. Therefore, the ETA could not always be calculated. Due to that, the ATTAS was adapting its flight path to the initial prediction. If the change in the prediction was too big, the difference could not be compensated for with airspeed only. That was the main reason why the

ATTAS arrived too late at the merge point in the trials. An example is shown in the sixth data row of TAB 1. 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, it actually arrived 24s later than the ATRA). The fourth column shows the difference in the ATA. The goal was always to achieve a difference in ATA between 5 and 15 seconds.

Leading Aircraft	RWY used	ATA-ETA	Delta ATA
Be350	08	-10s	14s
Be350	26	-1s	6s
Be350	08	-15s	9s
Be350	08	-11s	8s
ATRA	08	-4s	12s
ATRA	08	-15s	24s
ATRA	26	-2s	12s

TAB 1. Flight Test Results

It can be seen that in one 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, huge adaption cannot be compensated easily solely based on change in airspeed. In the other cases presented here, the ATTAS was able to reach the target time window at the merge point. Taking all approaches into account, there was a success rate of 60%.

One major issue during the trials was the degraded ADS-B reception in the ATTAS during the setup where the ADS-B receiver was on board. Only one experimental antenna could be used which was not providing optimal reception. In addition, the effects of antenna attitude in terms of shadowing played an important role during the trials. The effect was worst during the initiation of the procedure while the distance between the two aircraft was the biggest. During the 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 (up to 80%).

4. DISCUSSION

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 basis for a good prediction is a broadcast of a highly precise position through GNSS augmentation systems like EGNOS (as stated in [11]). Additionally, a high update rate (i.e., more than the typical rate of 1Hz or 2Hz) could assist in enhancing the prediction. This parameter is the most important one as the 4D-FMS is guiding the trailing aircraft to the merge point with this ETA as time constraint. Therefore, even the most precise time guidance on board the trailing aircraft could not compensate large errors in the ETA prediction of the leading aircraft.

In the flight trials with two simultaneously approaching aircraft presented in this work 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.

The briefings conducted during the trials were exhaustive and the crews stated that they were well informed. The go-around/escape procedure was clear and communicated in every briefing. Therefore, the overall risk during the trials was low and the trials could be conducted safely and successfully.

If the two presented 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 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. In contrast to the highly precise guidance provided on board of the ATRA (4D-FMS with flight director guidance) the experimental setup seems less sophisticated and therefore, greater time errors were expected. The trials showed however, 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

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 good 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.

5. CONCLUSION

The flight trials carried out in this work show that it is possible to perform the designed approach procedure. Therefore, closely spaced parallel approaches could be carried out even in IMC. This could improve runway capacity at a given airport. Still it has to be stated that several adaptions had to be made to conduct the presented flight trials. In the trials the leading aircraft had a certain set of constraints which are usually not as strict during a standard approach procedure.

Additionally, the performance of the navigation system could influence this approach procedure if no visual flight conditions are present. Both aircraft are required to maintain certain accuracy values with certain integrity values for a given procedure. Augmented GNSS positioning methods could enable these parallel approach procedures (see [12]).

It can be stated that the described flight test methods can be used to verify simultaneous, closely spaced approach procedures. The private company frequency was very helpful during the trials for timing purposes and the situational awareness of the pilots.

During the trials no wake encounter was experienced and no emergency escape maneuvers had to be initiated which shows that using a buildup approach with adding only single elements to the trials is a safe way to investigate a complex system.

Future investigations could focus on the removal of all constraints for the leading aircraft so that the 4D-FMS relies solely on the ETA prediction and the resulting path and speed adaptions. On the other hand, it could also be investigated if the transmission of an ETA of 4D-capable aircraft with a certain update rate could improve the execution of this procedure. In terms of a collaborative Air Traffic Management (ATM) this would be a good way to enable the proposed approach procedures with a high precision.

6. AKNOWLEDEMENTS

The authors would like to thank the great number of people who were involved in these trials. This includes the developers of the different systems on board of the different aircraft as well as the flight crews and ATC staff at the airport and at the area control center who were very helpful and flexible throughout the trials.

7. ABBREVIATIONS

ADS-B	Automatic Dependent Surveillance Broadcast
AHMI	Airborne Human Machine Interface
ATA	Actual Time of Arrival
ATC	Air Traffic Control
ATM	Air Traffic Management
ATRA	Advanced Technologies Research Aircraft
ATTAS	Advanced Technologies Testing Aircraft System
CDA	Continuous Descent Approach
DGPS	Differential GPS
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
DWD	Deutscher Wetterdienst
ETA	Estimated Time of Arrival
FAP	Final Approach Point
FCS	Flight Calibration Services
FL	Flight Level
FMS	Flight Management System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAF	Initial Approach Fix
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
LDLP	Low Drag Low Power
MSL	Mean Sea Level
PFD	Primary Flight Display
RNAV	Area Navigation
RWY	Runway
SCDA	Steep Continuous Descent Approach
TCAS	Traffic Alert and Collision Avoidance System
TIS-B	Traffic Information Service Broadcast
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
WTMA	Wake Turbulence Mitigation for Arrivals

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