



Executive summary

Enabling Technology Evaluation for Efficient Advanced Continuous Descent Approaches



Abstract

This paper describes the development and validation of environmentally efficient advanced Continuous Descent Approach procedures in a future high density operational environment for Amsterdam Airport Schiphol. Efficient CDA operations under such conditions are promoted by the combined use of new and/or available enabling airborne and air traffic management technologies. This includes FMS CDA and RTA functions, cockpit display cues, air-ground data-link and time based arrival management by means of advanced AMAN, RNAV STARS and a traffic flow sequencing and merging controller support tool.

Validation was carried out using fast time capacity and safety simulations, as well as during real-time human-in-the-loop simulation exercises, the latter involving both air traffic controllers and flight crews. The evaluation showed promising results with respect to the feasibility of the concept to achieve medium to high density CDA traffic flows. Supporting environmental

assessments showed that, if such procedures could be implemented at full scale, reductions of up to 20% of the overall airport noise footprint could be obtained.

The work has been carried out within the OPTIMAL project (Optimised Procedures and Techniques for Improvement of Approach and Landing), a European 6th Framework Program research project (2004-2008) which develops innovative procedures for the approach and landing phases of aircraft and rotorcraft. The project objective is to minimize environmental impact and increase airport capacity while improving operational safety. OPTIMAL is an air-ground cooperative project developing both airborne and ground systems and their interoperability.

The results from this project are being taken forward within other follow-on projects and the SESAR programme.

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Enabling Technology Evaluation for Efficient Advanced Continuous Descent Approaches

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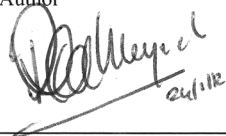

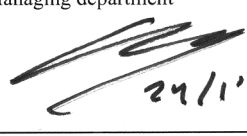
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ENABLING TECHNOLOGY EVALUATION FOR EFFICIENT CONTINUOUS DESCENT APPROACHES

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Abstract

This paper describes the development and validation of environmentally efficient advanced Continuous Descent Approach operations in a future high density operational environment for Amsterdam Airport Schiphol. Efficient CDA operations under such conditions are promoted by the combined use of new and/or available enabling airborne and air traffic management technologies. This includes FMS CDA and RTA functions, cockpit display cues, air-ground data-link and time based arrival management by means of advanced AMAN, RNAV STARS and a traffic flow sequencing and merging controller support tool.

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Abbreviations

ACDA	Advanced Continuous Descent Approach
AMAN	Arrival Manager
ASAS	Airborne Separation Assistance System
ATM	Air Traffic Management
CDA	Continuous Descent Approach
CORADA	Converging Runways and Approaches Display Aid
FMS	Flight Management System
IAF	Initial Approach Fix
OPTIMAL	Optimised Procedures and Techniques for Improvement of Approach and Landing
RNAV	Area Navigation
RTA	Required Time of Arrival
TMA	Terminal (Manoeuvring) Area

1 Introduction

With the projected growth of air traffic for the coming years, airport congestion and the environmental impact are a mounting problem and already are a limiting factor at some airports. Throughout the world, much effort is being undertaken to increase the usage of Continuous Descent Approaches (CDA) at more airports. This type of operation can provide significant reductions to community nuisance while improving the fuel economy in the approach.

The CDA procedure helps in this context by flying higher and with less noise compared to present day conventional operations. The principle is that aircraft approaching an airport follow a continuous descent profile at a (near) idle thrust setting, with no level segments at low altitudes. The higher approach profile combined

with a reduced engine and aerodynamic noise significantly decreases noise exposure around airports. Comparative studies indicate possible noise reduction from 3dB to 8dB compared to conventional operations, including reduced fuel consumption and particle emissions in the terminal airspace. However, there are still many issues to realise this type of operation during high-density traffic at different airports:

- Present air traffic control procedures and technology do not easily allow flying such procedures except during night time when there is less traffic.
- No standard operating procedures are yet in place to perform CDA procedures in a repeatable manner.
- Aircraft are not always equipped to take full advantage of this way of operation.

Many simulation and also operational CDA trials are being carried out at different airports in the world, e.g. Amsterdam, Stockholm Zurich and Louisville. Basic CDA is in operation at the London airports and efforts are being made to introduce such operations elsewhere. However, local specifics make it difficult to come to a universally applicable mode of operation in the terminal area. For instance, flight operations in the London area are greatly supported by the availability of stacks before commencing basic CDA's, whereas Frankfurt arrivals are based on RNAV transitions, and Amsterdam Schiphol operations extensively rely on radar vectoring for efficient operation.

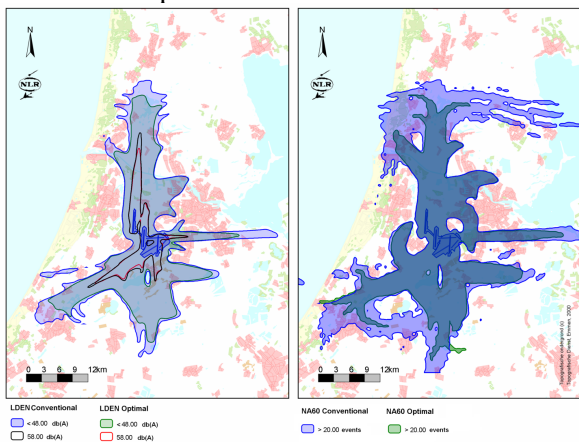


Figure 1: Noise impact at Schiphol airport, comparison of noise footprints between conventional and ACDA ops.

One of the research objectives within the OPTIMAL project [1] is to validate and demonstrate that noise and emissions friendlier CDA procedures can be applied successfully during busier (normal/heavy) traffic conditions, by further developing:

- CDA operating procedures so they can be flown in busy traffic in a standardised and repeatable manner
- Onboard systems and functions to plan and fly the defined CDA
- Ground systems to support high density CDA operations
- Suitable interoperability between air and ground systems.

2 ACDA procedure and operational concept

The following paragraphs give an overview of the applied CDA procedure and the operational concept within a generic airport environment.

2.1 Descent profile definition

Continuing on the experiences obtained from earlier projects (most notably Sourdis II [2]), two CDA descent profiles were selected for the present study. The so-called *optimised* CDA offers most noise reduction with a fully idle descent, however presently at a loss of capacity, whereas the *nominal* CDA provides better compatibility with the present ATM system for reasons of predictability and repeatability, while some speed control remains possible.

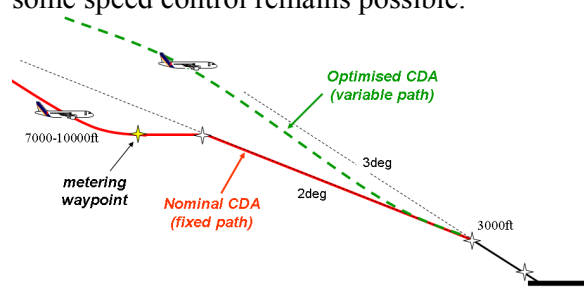


Figure 2: Nominal/Optimised CDA profiles

The study focuses primarily on the integration of the nominal CDA procedure into the ATM system, as this procedure is expected to provide the best compromise between airspace and groundside capabilities, thus facilitating an easier integration in the medium term.

Note that the present project focuses on the implementation of environmentally friendly operations in terminal airspace around airports, specifically more silent initial approaches down to an altitude of around 2000ft. This is an area where considerable noise reduction can be achieved compared to current operations.

2.2 Integration into the ATM System

Efficient day-time operation of advanced CDA procedures requires implementation of a set of enablers and operational procedures at the same time.

On the aircraft side, to allow the FMS to efficiently plan the (near) idle CDA profile, a prescribed arrival trajectory has to be available, at minimum from the CDA top-of-descent to final approach. Once started, the CDA profile should not be intervened by ATC unless in case of impending loss of separation. The solution chosen for this concept is to use RNAV routes from top-of-descent to the final approach replacing conventional radar vectoring.

On the ground, to ensure safe separations in the sequence of decelerating approaches, arriving traffic needs to be properly sequenced to arrive over the runway threshold with the appropriate minimum spacing. This requires a highly accurate arrival planning compared to present day vectoring where late final adjustments can be made by the controller.

Such advanced CDA operations therefore require suitable ATC planning tools, preferably using trajectory planning data from the onboard FMS, which is sent from the aircraft to ATC by means of data-link. In the present concept the FMS Estimated Time of Arrival was used for arrival management.

Additionally, as ATC needs to reduce the use of vectoring to a minimum in this concept, a tool to support the monitoring and execution of traffic flow merging is needed to provide sufficient awareness to the ATC controller.

2.3 Airspace and airport considerations

While previous projects such as [2] have already provided good indications on the feasibility to operate CDA approaches within the terminal area, the present project extends the scope of the

evaluation. The following airport and airspace layout was created:

- Generic and sufficiently large extended terminal airspace, without the limitations and restrictions specific for individual airports.
- Start of arrival management before top-of-descent. Within the scope of the present concept, the arrival management horizon was set to a distance of around 120NM from the airport.
- Pre-defined arrivals and transitions are in place from cruise top-of-descent to the final approach. Sequencing activities should be preferably accommodated by means of RNAV based path stretching, speed instructions, RTA instructions or a combination of these.
- For best gradual transition from present day vectoring techniques in the TMA to fixed routing, daytime RNAV transitions were derived from typical average vector tracks. Note that these routes are not necessarily optimised towards noise abatement.
- The target minimum landing capacity for the initial concept evaluation assumes 30 per hour per runway with peaks of 33/hr per runway.
- The CDA nominal descent profile to the runway starts at 7000ft above ground.

The described generic airspace was applied to a possible future Airport Schiphol situation to validate the feasibility of the concept for parallel runway operations (see Figure 3).

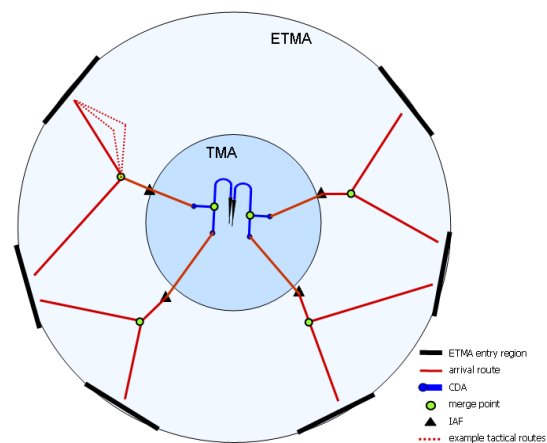


Figure 3: Generic airspace design



Within this concept both TMA and extended TMA are divided into suitable controller sectors.

2.4 Selection of enabling technologies

With the above airspace and routing concept, a further set of potential enablers may be needed to achieve the desired throughput. A fast-time simulation study on required separations during RNAV CDA's indicated a required punctuality of $\pm 30s$ at the initial approach fix for this particular airspace and prevailing winds. In order to meet this accuracy in arrival management, the following technical enablers were selected for evaluation in the concept:

- Advanced arrival manager (AMAN) for accurate strategic planning of the CDA approaches and with specific additions for RNAV based sequencing.
- Air-ground data-link communications to take into account available onboard data.
- Converging Runways and Approaches Display Aid (CORADA) to assist the executive controllers during their tactical sequencing and merging.
- Use of Required Time of Arrival by equipped aircraft to achieve time over Initial Approach Fix (IAF) and/or over the runway threshold.
- Use of Airborne Separation Assistance System (ASAS) Merging and Spacing by equipped aircraft to achieve merging at the metering fix and achieve a relative time spacing over the threshold.

For the validation, different combinations of the aforementioned enablers were put to the test to assess the feasibility and potential benefits.

3 Concept validation activities

As part of the overall validation of the concept, several safety-oriented, environmental and capacity evaluations were carried out. These exploratory assessments were followed by several real-time human-in-the-loop concept evaluations involving both ATC controllers and pilots. These evaluations were carried out on NLR's NARSIM ATC Research Simulator,

GRACE moving base and APERO fixed based research flight simulator.

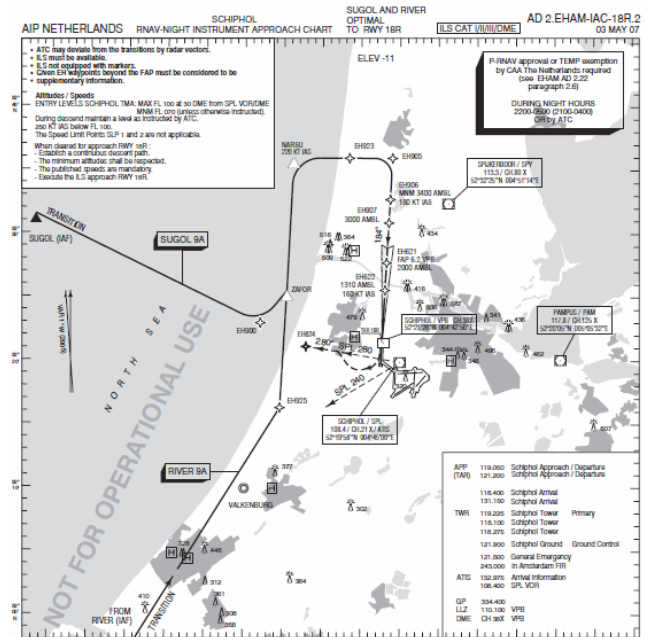


Figure 4: Concept CDA RNAV transitions to rwy18R at Schiphol airport

The first phase of these evaluations has focused on the final traffic flow merging and safe execution of RNAV CDA approaches in terminal airspace, whereas the second phase evaluates sequencing and merging between top-of-descent and metering fixes.

Based on initial results as described in [2] and [3], a comparison airport scale study was carried out to assess obtainable environmental benefits if full scale CDA operations could be implemented according to the proposed concept. Figure 1 shows a comparison of footprints for different noise metrics between conventional and full scale implemented CDA operations.

These indicative results show a positive trend in noise reduction, with an overall noise footprint reduction up to 20%.

3.1 Safety evaluation of CDA operations

In preparation of the planned human-in-the-loop evaluations and to obtain parameter settings for the CORADA sequencing tool, a safety assessment of in-trail separations during CDA approaches has been carried out using an NLR developed Monte-Carlo simulation.

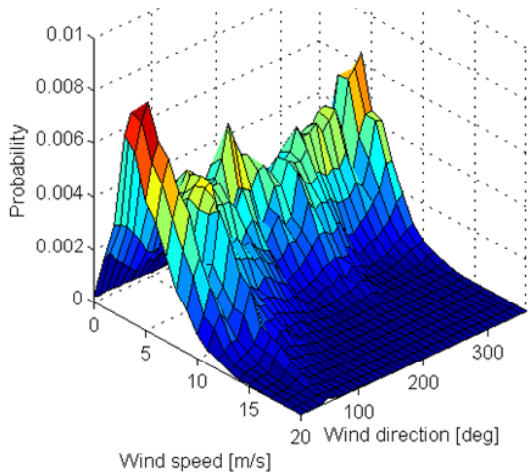


Figure 5: Probability density function for wind speed and direction at Schiphol airport, based on hourly measurement data in the period 1976-2005.

This Monte-Carlo CDA simulation takes into account variations in many parameters,

such as navigation accuracy, aircraft types, landing weights, aircraft performance and prevailing wind conditions. Note that the calculations have been carried out assuming for instance the specific arrival routing as indicated in Figure 4 and typical wind conditions at Schiphol airport as depicted in Figure 5. Results may therefore be different depending on the local situation thus influencing theoretically achievable maximum runway throughput.

Figure 6 gives a sample of the Monte-Carlo simulation results for a given combination of navigation and timing accuracy, traffic load and initial separation distribution. Note that a small percentage of arrival combinations in the (open loop) M-C study would result in less than minimum required separation distances. This was deemed acceptable by controllers, while correctable by ATC controller interaction during actual conditions.

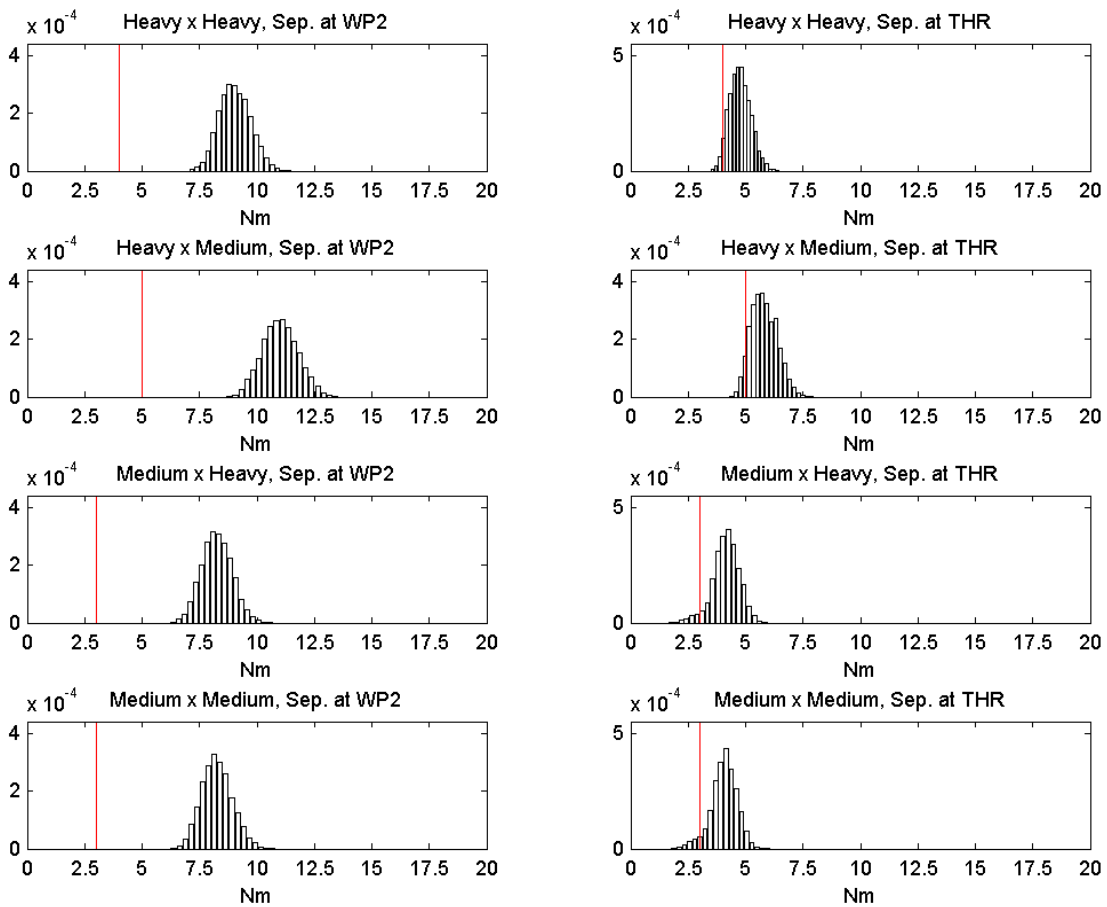


Figure 6: Example histograms of separation distances from Monte-Carlo simulation. Separation is shown at WP2 (left, waypoint EH900 in Fig. 4, before start of CDA) and at runway threshold (right) for combinations of heavy and medium leader-follower aircraft pairs. Red lines indicate ICAO separation minima.

From these results a dedicated CDA in-trail separation table was made to obtain safe in-trail separation distances between aircraft at the start of the CDA in order not to violate prescribed ICAO minimum separation distances at the end of the CDA profile at runway threshold. The values in the table were subsequently used as an input for the minimum required stagger distance settings within the CORADA tool.

3.2 Supporting tools for ATC

For the purpose of providing the executive ATC controller better awareness with respect to merging of traffic flows including the desired separations prior to the start of the CDA, a dedicated tactical monitoring tool named CORADA was developed. This tool extends its original application area for converging runway operations during low visibility conditions to a much broader use in general merging of traffic during arrival and approach.

By applying the minimum CDA stagger distances between two successive aircraft (as discussed in par. 3.1), and projecting these on the radar screen, the controller is graphically presented the desired spacing to aim for. An indication of the concept is given in Figure 7.

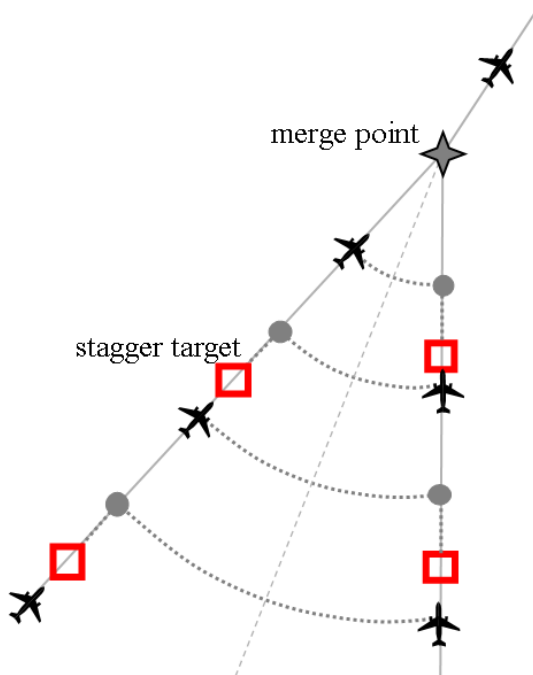


Figure 7: CORADA merging concept

Merge point ZAFOR (see fig. 4) was used during the simulator evaluations to merge traffic flows coming from IAFs RIVER and SUGOL.

The final merging process in the terminal airspace requires the flow of traffic to arrive more punctually and consequently sufficiently smoothed at TMA entry. Using the NLR developed arrival manager with the added enablers, the inbound sequence is built in the extended TMA, with final merging in the TMA. This has the aim to reduce the need for large scale final vectoring in the TMA. This requires a shift from vectoring towards accurate time based operations in the TMA with a target for realised times over the IAF within ± 30 sec.

3.3 CDA operations in the TMA

As a first step in the human-in-the-loop concept evaluations the feasibility of performing CDAs in a busy terminal area was evaluated by a group of active approach controllers on the NLR ATC Research Simulator NARSIM as well as using NLR's GRACE research flight simulator simulating an A330 aircraft.

For the traffic sample that was offered to the controllers, the assumption was made that traffic arriving at the TMA entry waypoints was provided with the timing accuracy as indicated before. The feasibility of the scenarios had also been verified on an overall airport and airspace scale during fast-time capacity simulations using the Total Airport and Airspace Modeler (TAAM).

During the evaluations in the terminal airspace, arriving traffic should follow the RNAV transitions as much as practicable, with minimum additional vectoring by ATC. Controllers were briefed to provide speed instructions as a preference, to keep the aircraft on the prescribed RNAV routing, although heading instructions could be given if needed. The evaluations showed that, while speed and/or heading instructions were often needed, the final sequencing could be completed prior to the start of the RNAV CDA descent (at 28NM from the runway threshold). The trials provided a good indication to achieve an acceptable runway throughput performing uninterrupted CDA's of

at least 33 landings per hour per runway with the given configuration of airspace and routing.

The flight deck specific aspects of the operational concept and execution of the CDA procedure were evaluated by active flight crews on the A330 based flight simulator which was enhanced with a number of supporting tools. These included dedicated speed based configuration cueing mechanisms for the most efficient execution and monitoring of configuration changes, as well as exploring the use of the ASAS Merging and Spacing function for time-based spacing (controlling a relative time) and the RTA function for time-based navigation (controlling an absolute time).

Figure 8 gives an example of the usage of configuration cues on the PFD speed tape, to advise the pilot about next configuration change moment (including gear extension). Dynamic configuration speeds were used to optimise the time planning of the CDA down to the runway threshold. The nominal value of the cues was chosen 10 knots above minimum manoeuvring speed.

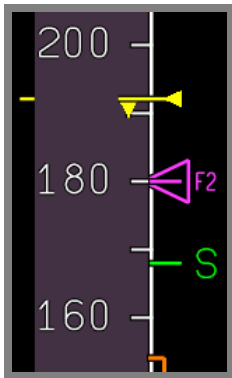


Figure 8: F2 cue on speed tape

Figure 9 presents the indication of the ASAS spacing error with respect to the lead aircraft as shown on the Navigation Display. The calculated optimal follow speed could be fed into the flight guidance system and be flown by the autopilot/auto throttle system.

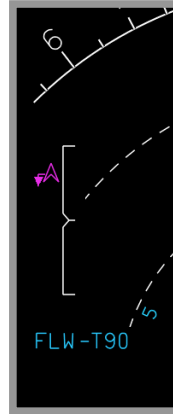


Figure 9: ASAS time spacing error indication

Overall, supporting tools and operational concept were well received and highly accepted, but with areas for improvement. Comments were given that effective monitoring of planned versus actual speed profile and predictability of actions with the slow CDA deceleration profile sometimes remained difficult. Also, even when necessary, the use of ATC speed constraints should be kept to a minimum for optimal CDA operations.

3.4 Extended TMA Arrival Management

Following the promising results from the TMA only evaluations, the next phase of simulations aimed at evaluating a set of enablers to improve the overall operation of inbound traffic from top-of-descent to touchdown. The goal of the eTMA simulations was to achieve the desired improvement of the TMA metering accuracy to within ± 30 sec, as well as an improvement of the resulting flow of CDA traffic in terminal airspace as a result of the interactions between the different area and approach control sectors. For the baseline scenario for 2015, an accurate arrival planning tool (AMAN) was available by default to the supervisor, and CORADA tactical support was available to the approach controller in the TMA. In addition to these, the following variables during the simulations, carried out on both the NLR ATC and flight simulators, were evaluated on their benefits:

- RNAV based path stretching (“doglegs”) in the extended TMA to allow optimum use of onboard automation.

- Use of CORADA in the extended TMA to improve controller awareness on the overall arrival sequencing over different control sectors towards the TMA.
- Delegated arrival timing using the on-board RTA function, with coordinated arrival times and routing through data-link communication with the supervisor.

The ATC and flight simulator trials were carried out during the period of September 2007 to May 2008. On the ground side, a group of four active controllers was involved to manage an entire flow of traffic onto one of the two landing runways in the scenario. Traffic flows for the second landing runway was assumed “mirrored” and independent of the runway used for the evaluations (Figure 3). Two executive area (ACC) controllers manned the two E-TMA sectors feeding incoming arrivals to the TMA approach (APP) controller. Overall operation and arrival planning was monitored by the supervisor who could make use of the AMAN arrival scheduler as shown in Figure 10. To provide valuable input from an airborne perspective, eight flight crews participated on the flight simulator.

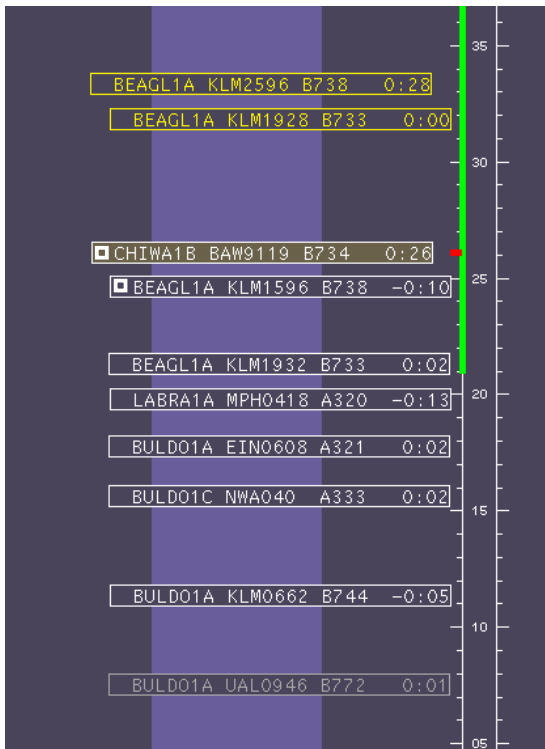


Figure 10: AMAN arrival scheduler HMI

Path stretching legs and optional RTA at the IAF’s were provided by ATC for proper separation and sequencing. Additional fine-tuning in time was accomplished by on-board speed control.

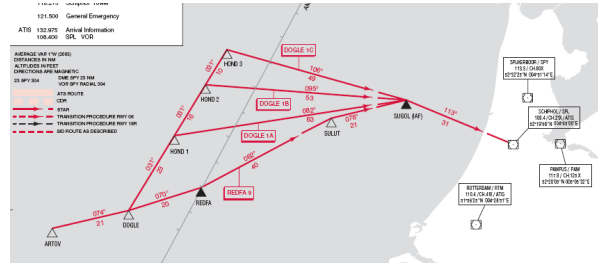


Figure 11: RNAV based path stretching legs

Overall, the introduction of RNAV based *doglegs* was preferred by pilots over the current practise of vectoring. However, pilots stressed that from a flight efficiency point of view, priorities for sequencing aircraft in initial descent should be:

- Early speed control optionally followed by path stretching (only after reduction to minimum clean speed) when a delay is required
- Path shortening optionally followed by speed control when a reduction of separation is desired.

Recorded track data showed the additional flown distance in the TMA to be largest for the baseline scenarios (using only AMAN in the extended TMA), which implies an improved performance for all (combinations of) additional enablers. Furthermore, a high punctuality could be achieved, in particular with the combined use of RTA. Overall, this resulted in higher throughput results compared to the baseline scenario.

The use of CORADA in the extended TMA, contrary to the easy and straightforward use in the TMA, proved more difficult than expected. As the controllers were instructed to use (relative) CORADA stagger targets in the extended TMA for optimum sequencing, it proved that this could be confusing in relation to the (absolute) target arrival times as provided by the AMAN planning which was frozen at a

given moment. Also, disturbance propagation between air traffic control sectors could occur as a stagger target for a given aircraft under radar control of one sector can be linked to an arriving aircraft under control of another sector. The (need for) reducing this interaction has to be investigated in more detail. On the other hand, whereas the target arrival times were less accurately met when using CORADA in the extended TMA, the final sequencing needed within the TMA was reduced. Relative spacing methods appear to be better suited to deliver aircraft to the terminal area.

4 Conclusion

Various ATC and flight simulations were carried out to evaluate the concept of operating ACDA procedures in a realistic future traffic environment. The advanced Continuous Descent Approach is really a promising procedure in terms of noise abatement and environmental improvement near airports. This procedure could be applied in a very short-term and has also been selected in the SESAR operational concept. Advanced CDA operations will be part of the future ATM system.

References

- [1] OPTIMAL project, www.optimal.isdefe.es
- [2] Den Boer R G, et al. *Sourdine II D9-1 Final Report*. Version 1.1, National Aerospace Laboratory NLR, 2006, www.sourdine.org.
- [3] Van Boven M. Development of noise abatement approach procedures. *10th AIAA/CEAS Aeroacoustics Conference*, Manchester, UK, AIAA-2004-2810.

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