Nationaal Lucht- en Ruimtevaartlaboratorium

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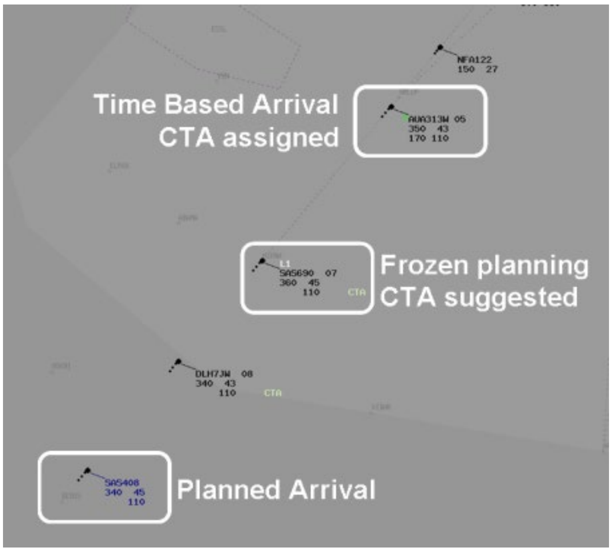
Executive summary

Implementing time based CDA operations in a medium-high density ATM environment



Report no.
NLR-TP-2012-297

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Report classification
UNCLASSIFIED

Date
August 2012

Knowledge area(s)
Luchtverkeersmanagement(ATM)- en luchthavensimulatie en -validatie
Luchtverkeersmanagement(ATM)- en luchthavenoperaties
Training, Missiesimulatie en Operator Performance

Descriptor(s)
Time Based Operations
Continuous Descent Approach
Arrival Management
Controlled Time of Arrival

Problem area
Within the present air traffic management (ATM) system, a desired high capacity rate of continuous descent operations, flown from top-of-descent to final approach, is not yet feasible during daytime operations at major airports. A concept of operations is described aiming at reducing the aviation environmental impact through better planning and predictability in the (extended) terminal area. This should enable a higher rate of Continuous Descent Approach (CDA) profiles while maintaining at least the same rate of Continuous Climb Departures. The work was performed within the ERAT project (Environmentally Responsible Air Transport), sponsored by the European Commission. The project aims to achieve enhanced climb and descent services as defined by SESAR and for implementation of operational improvements in the short to medium term.

Description of work
Key elements in the concept of operation for medium to high density CDA operations are time based operations using Controlled Time of Arrival (CTA), applying advanced arrival management and trajectory prediction, as well as integrated controller support tools.

This report is based on a presentation to be held at the 28th Congress of the International Council of the Aeronautical Sciences (ICAS), Brisbane (Australia), 23-28 September 2012.

After extensive preparations and prototyping sessions of the time based concept and the associated new ATC support tools, in total two weeks of real time ATC simulations were carried out in 2010 on the NARSIM platforms at LFV in Malmö and NLR in Amsterdam. Each evaluation session involved 6 active ATC controllers and 5-7 pseudo pilots.

Results and conclusions

The obtained results clearly showed that the time based CDA concept is well feasible with the offered medium traffic flow density of on average 32 landings per hour, including higher traffic peaks. About 20% more PRNAV based CDA's were observed when using the time based concept and support tools, compared to conventional procedures.

The evaluations have definitely proven benefits of the concept regarding predictability and efficiency. The concept and the advanced arrival management tool that have to support the concept seem to cater for possibilities to reach higher efficiency.

Applicability

The experiences gained with the real-time ATC simulations have considerably supported the validation of a time based CDA concept at Stockholm Arlanda and improved the concept as well as supporting technology. The obtained experiences will be applied in follow-on projects, at Arlanda and other European airports, and within the SESAR programme.

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Implementing time based CDA operations in a medium-high density ATM environment

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Customer	Directoraat-Generaal Luchtvaart en Maritieme Zaken
Contract number	----
Owner	NLR + partner(s)
Division NLR	Air Transport
Distribution	Unlimited
Classification of title	Unclassified
	August 2012

Approved by:

Author	Reviewer	Managing department
R.J. de Muynck	T.J.J. Bos	ATAP
Date: 6-8-2012	Date: 6-8-2012	Date: 8-8-2012

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IMPLEMENTING TIME BASED CDA OPERATIONS IN A MEDIUM-HIGH DENSITY ATM ENVIRONMENT

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Keywords: *Time Based Operation, Arrival Management, Controlled Time of Arrival, Continuous Descent Operation*

Abstract

Within the present air traffic management (ATM) system, a desired high capacity rate of continuous descent operations, flown from top-of-descent to final approach, is not yet feasible during daytime operations at the major airports. A concept of operations is described aiming at reducing the aviation environmental impact through better planning and predictability in the (extended) terminal area. This should enable a higher rate of Continuous Descent Approach (CDA) profiles while maintaining at least the same rate of Continuous Climb Departures. The work was performed within the ERAT project (Environmentally Responsible Air Transport), sponsored by the European Commission. The project aims to achieve enhanced climb and descent services as defined by SESAR and for implementation of operational improvements in the short to medium term. Key elements in the concept of operation for medium to high density CDA operations are time based operations using Controlled Time of Arrival (CTA), applying advanced arrival management and trajectory prediction, as well as integrated controller support tools. The evaluations have definitely proven benefits of the concept regarding predictability and efficiency. The concept and the advanced arrival management tool that have to support the concept seem to cater for possibilities to reach higher efficiency.

1 Introduction

Recent decades have shown a considerable growth of worldwide air traffic, both by accommodating a larger number of aircraft in the air and through expansion of the airports. Within Europe, with its dense population, continued growth of air traffic is becoming more and more an environmental burden due to the difficulty to avoid the close vicinity of major airports to populated areas. A reduction of this negative impact on society in terms of noise and emissions needs to be addressed by the aviation stakeholders who need to search for an environmentally sustainable growth as integral part of their strategy. Such a growth can be achieved by mandating and introducing more economic and quieter aircraft types, but also by implementing environmentally friendlier and more efficient operations of the overall air traffic system.

In the vicinity of the airports the ideal situation would be achieved by optimised climb and descent profiles, also during peak hours. Continuous Descent (CD) flight profiles flown are currently insufficiently predictable within the existing air traffic management system to merge within a tightly orchestrated arrival flow around busy airports. In addition, the objective is also to at least maintain or enable continuous climbing departure profiles. Any restriction to departing traffic to better facilitate continuous descents may easily offset the benefits gained on the arrival side.

Within the EU sponsored FP6 project ERAT (Environmentally Responsible Air Transport), the project partners have teamed up to prepare and validate the operational context for enhanced climb and descent services for two major airports as defined in the Single European Sky ATM Research (SESAR) project. As part of ERAT, Sweden's Air Navigation Service provider LFV, with the cooperation of DLR, NLR and the other project partners, have developed and validated an operational concept, controller tools and procedures to implement Continuous Descent operations under higher traffic conditions.

Based on previous experiences to evaluate more predictable continuous descent operations in other projects, eg CASSIS [1], TMA2010+ [2][3][4], SARA [5], OPTIMAL [6] and SOURDINE II [7], work was continued towards a suitable operational concept. In line with SESAR, a time based concept and associated concept elements were developed to achieve continuous descents under medium-high traffic conditions in the extended terminal airspace (TMA) of Stockholm Arlanda airport.

The following sections describe concept, concept elements and evaluation results from real-time ATC simulations which were carried out with the participation of active controllers.

2 Concept for Time Based CDA Operations

The concept of time based continuous descent operations has been developed [8] and applied to the Stockholm Arlanda airport and airspace environment. The concept applies the use of so-called Controlled Times of Arrival (CTA) as a time constraint for inbound aircraft to achieve a more orderly and predictable arrival sequence.

This CTA time constraint is applied to dedicated waypoints on the different arrival routes to the airport. Experience from previous projects had already been gained with a number of different CTA waypoint locations, e.g. the TMA entry fix, waypoints located around 20-40 NM or on the runway threshold. Based on the obtained feedback, it was regarded most optimal to use a CTA waypoint located at a distance of 30NM to the runway with the present state of technology and procedures. This distance would allow good possibilities to execute successful CDA approaches and still provide sufficient airspace after the CTA point for final corrections by the approach (APP) controllers, as necessary.

2.1 Generic Time Based Concept

An overview of the operational concept for a typical flight is indicated in fig. 1. The ground based arrival manager (AMAN) determines the optimum landing sequence based on available inbound flight plans and trajectory predictions

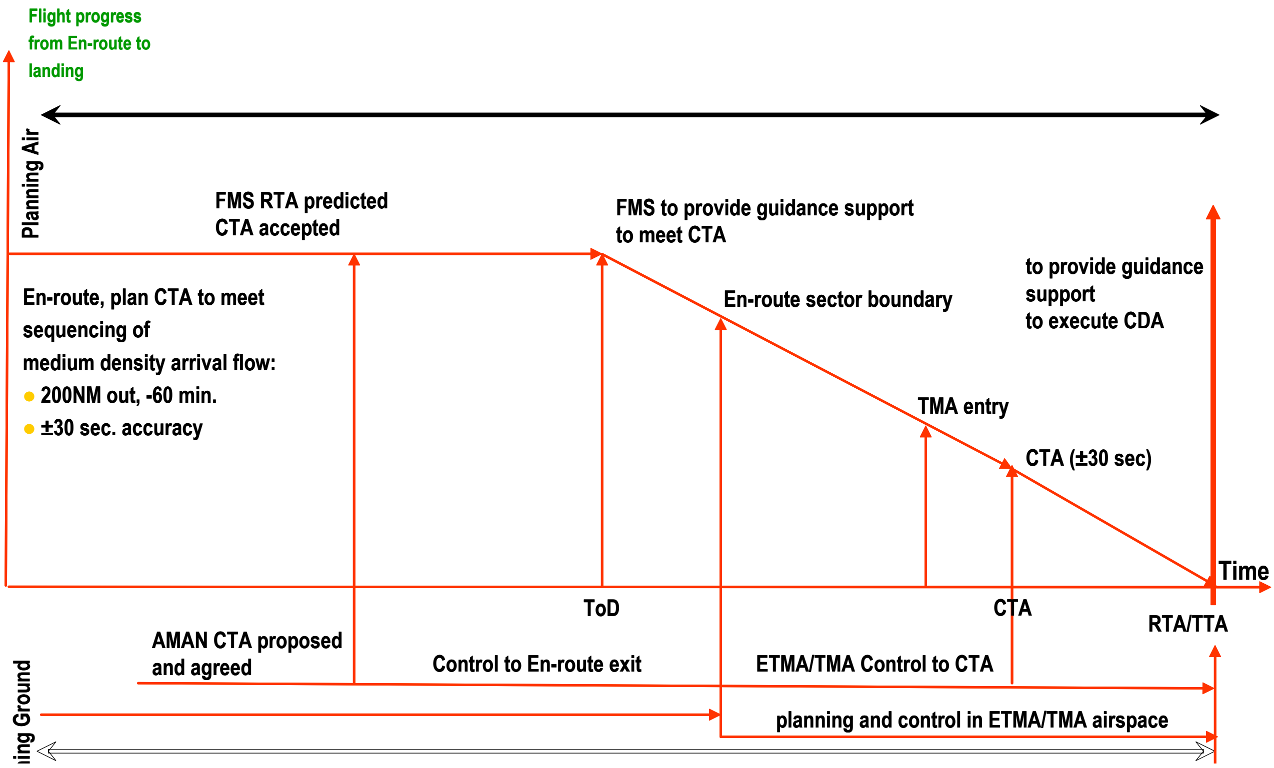

Fig. 1. Plan view of altitude vs. distance within time based operational concept

based on radar data. Based on the planned landing sequence a time constraint is calculated that needs to be achieved by inbound aircraft.

For a typical nominal arrival the sequence of events is then the following. Once within reasonable planning range, inbound aircraft for Stockholm Arlanda airport are taken into account by the AMAN in the arrival sequence planning. The aircraft are assigned a standard arrival route (STAR) to the landing runway and approximately 30-35 minutes before the estimated touchdown time, the AMAN freezes the landing sequence.

Based on the planned touchdown time the estimated time at the 30NM control waypoint can now be used as a 4D time constraint for the inbound aircraft. When executed with the desired timing accuracy, this helps to achieve an orderly planned arrival sequence of optimum descent profiles without excessive workload to the controllers. Fig. 2 shows the map around Stockholm Arlanda to indicate the scope of this concept into perspective.

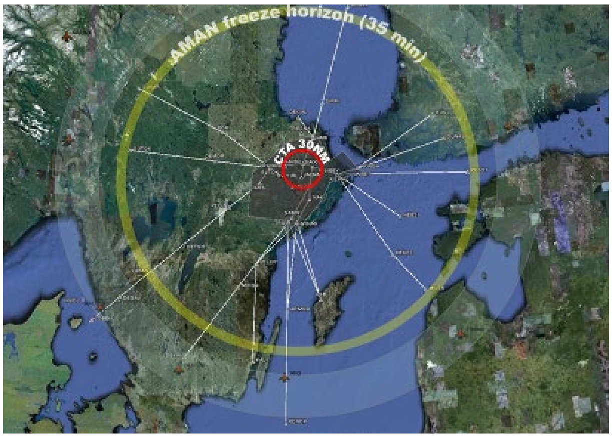

Fig. 2. Scope of Time Based Arrival Management at Stockholm Arlanda

2.2 ATC Operational Procedures

In the operational realisation of the concept the CTA time constraint, once frozen by the AMAN, can be issued by the en-route (ACC) controller to the aircraft once under his or her control. The flight crew enters and verifies the CTA time in the Flight Management System (FMS). If this constraint can be complied with in the descent profile, the aircraft will attempt to pass the CTA waypoint with ±30 sec accuracy under guidance of the FMS. The ACC controller also marks the CTA clearance in the system, which is shown with a dedicated 🕒 symbol in the aircraft label on the controller working position.

Under supervision and monitoring of ATC, and in case no traffic conflicts arise, the aircraft is allowed to fly an idle descent profile to meet the CTA time. After passing the 30NM control waypoint, the aircraft continues the optimum descent profile without further time constraint.

The operational concept and support tools should provide a robust environment for time based operation. Other traffic (departures, en-route and to/from other airports) should be handled, while disturbances and fluctuations in the arrival flow should be recoverable without severe interruptions. To achieve a safe operation of flight, speed, heading or altitude instructions may be issued by the controllers at any time.

2.3 Handling of Special Flights

It seems realistic to assume that there will always be traffic that cannot comply with a given CTA clearance, e.g. due to system limitation or malfunction, or due to an unfavourable moment of issuing the CTA clearance. ATC will then attempt to provide descent instructions to reach the target time at the CTA waypoint. To better support ATC controllers for the desired higher timing accuracy at the CTA waypoint compared to today, additional system support is provided in an improved controller working position.

Ideally, the landing sequence planning will be most predictable when all inbound flights are already in (stable cruise) flight. Special handling will be necessary for those flights with flight times similar to the AMAN planning horizon, i.e. with departure times just around the moment that the landing sequence should be frozen. The sequence number and arrival time of these flights can only be determined with sufficient certainty once the aircraft has become airborne. The associated uncertainty also affects sequence planning of arrivals scheduled just before or after. Within the developed concept, such "short" flights are taken into the planning before take-off by means of a provisional arrival time slot, which is applied to coordinate a target take-off time before departure.

3 Integrated Controller Working Positions

The Controller Working Positions for ACCAPP control are similar to those currently used at LFV in Arlanda, but with specific adaptations and improvements for the time base concept of operation.

Much effort was made to ensure that the necessary information and controller actions could be concentrated and presented in an integrated manner within the controller working positions. Prior to the actual evaluations, iterative prototyping was done to obtain a natural working interface with the essential information presented in the aircraft labels and in dedicated overview tables.

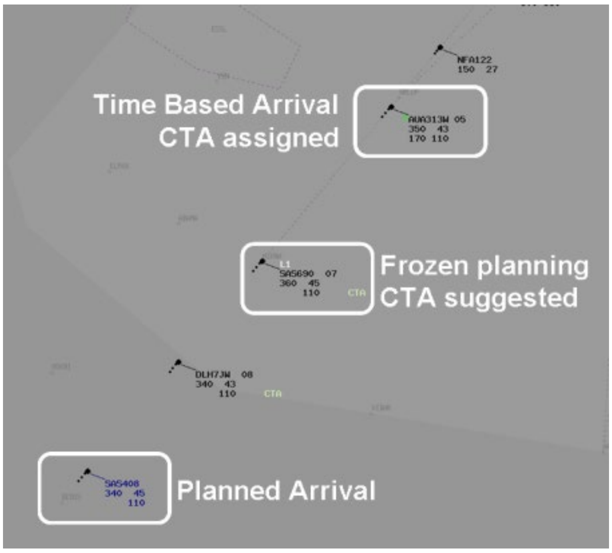

Fig. 3. Controller Working Position Radar Window, with aircraft labels in different states

In addition to the “normal” radar screens showing traffic for the relevant control sectors, an Arrival Sequence window was also available to the controllers, as can be seen in Fig. 4. This presents the planned arrival sequence by means of a “time-line” with aircraft information, assigned arrival routes and estimated time to lose or gain. This sequence and time information is also available on the radar screens, presented in the aircraft label or on mouse-over as shown in Fig. 3.

In actual operation, the concept would cover multiple en-route ATC sectors around Stockholm Arlanda airport. To keep the number of controllers required for a realistic evaluation to a reasonable amount, a number of sectors were combined during the simulations. While combining sectors could result in a higher workload than usual for these positions, this was compensated by using appropriately sized traffic samples for these sectors.

Six controller working positions were prepared for the following roles:

- APP West executive controller
- APP East executive controller
- APP final director
- APP coordinator
- ACC executive controller sector 3 (W)
- ACC executive controller sector 1 (E)

Rotation of the participating controllers was applied to collect opinions of the offered concept and working environment from different participants’ viewpoints. It was expected that familiarisation effects with the traffic samples would also be minimised as controllers were rotated.

4 Evaluation of the Time Based Concept

The feasibility and performance of the described concept was evaluated on various operational aspects during a series of real time ATC simulations.

The NLR ATC Research SIMulator (NARSIM) served during these evaluations as the central platform to control the overall simulation and provide a.o. the ground ATM infrastructure and controller working positions. Connected to the NARSIM, the DLR developed TrafficSim was used to generate all air traffic including the time based arrivals. The setup was configured with en-route and terminal airspace as well as airports around Stockholm Arlanda airport.

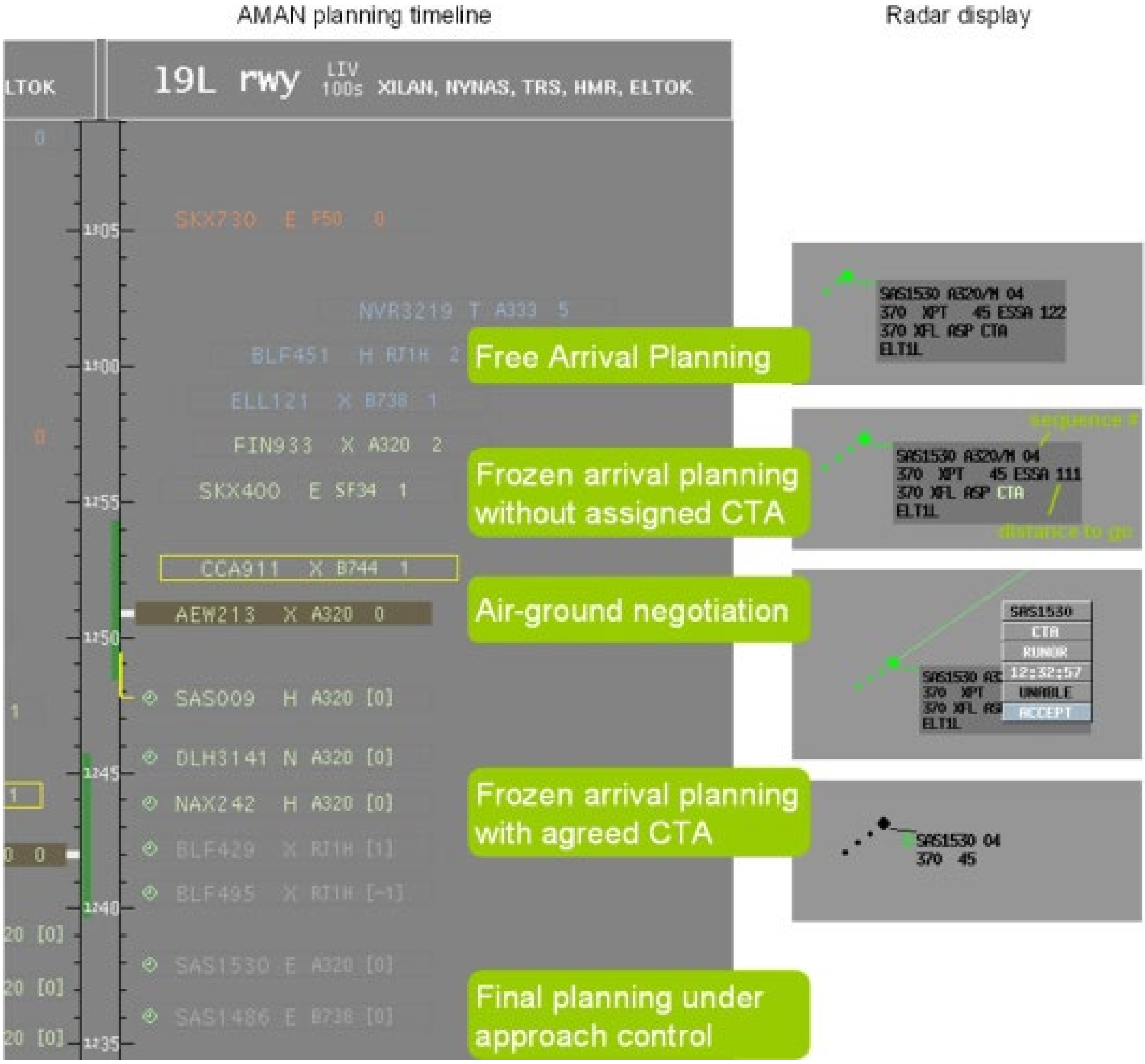

Fig. 4. Controller Working Position with Arrival Sequence Display, showing different stages of planning

4.1 Real-time ATC simulations

During two weeks of real time ATC simulations in total 27 measured evaluation runs were made. Both the prototyping and evaluation sessions were performed in 2010 with the participation of active ATC controllers from LFV. The first week of evaluations (RTS1) was carried out at LFV in Malmö, the second series of sessions (RTS2) were performed at NLR in Amsterdam. Feedback and comments given by controllers during RTS1 were taken into account in the follow-on preparations and improvements of the RTS2 simulation setup, support tools and traffic samples. The second series of sessions also attempted an additional further step forward by introduction of (RNP based) arrival routes, with a further reduction in track miles compared to the P-RNAV based STARs.

The simulator evaluations were aimed at investigating the feasibility of the concept under medium to high traffic density. Hereto the concept's impact was assessed on:

- Efficiency and environment in terms of:
  - Number of successful CDAs
  - Fuel consumption
- Operability by controller in terms of:

- Workload
- Situation Awareness
- Acceptability of concept, procedures and HMI.

For the real-time ATC simulations, the selected traffic scenarios included both inbound and outbound traffic for Arlanda, short haul flights and flights into a small nearby airport, as well as overflying traffic.

4.2 Simulated Airspace and Routes

The scope of the arrival management process was already indicated in Fig. 2. In reality this scope surpasses multiple ATC en-route sectors, in particular to the East with the neighbouring Finnish airspace. For the assignment of arrival time constraints this will normally require coordination. However for evaluation of the concept this was not regarded essential and not taken into account. The simulated en-route control sectors were therefore enlarged to cover the entire CTA allocation process.

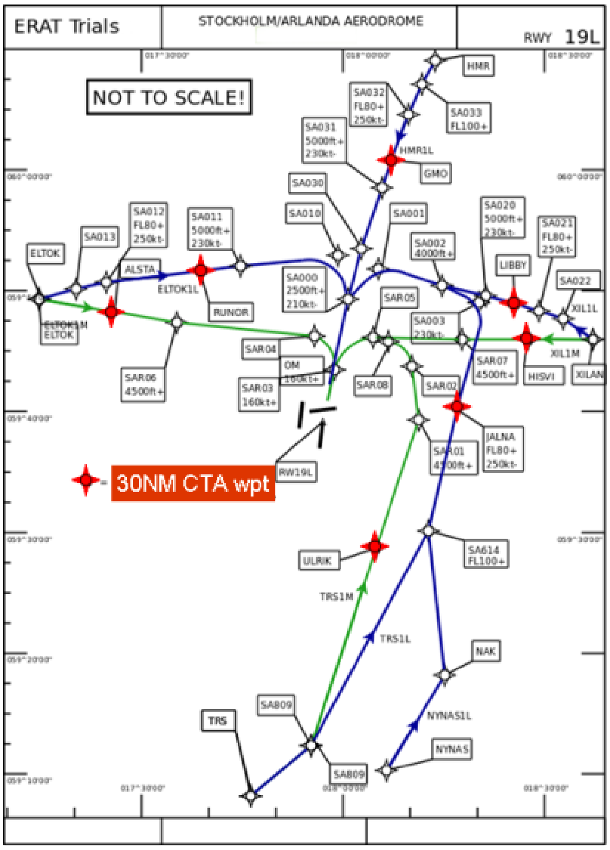

Fig. 5. Overview of evaluated P-RNAV and RNP arrival procedures in Stockholm terminal airspace

A single landing runway configuration was simulated at Stockholm Arlanda, resulting in using runway 19L for arriving traffic and 19R for departures. In addition, for traffic in and out of nearby Stockholm Bromma city airport, the runway in use for both take-off and landing was runway 12. The published standard instrument departure (SID) routes were used, although with a modification to the initial cleared SID altitude for better compatibility with the arrival routes.

Draft P-RNAV and RNP based standard arrival routes to runway 19L were designed for the present concept evaluation, since at the moment of the evaluation no published RNAV arrival routes existed for this runway. In addition, the special CTA control waypoints at 30NM were added to the procedure. Fig. 5 provides an overview of the final version of the arrival routes. Note that either the P-RNAV or RNP based arrival routes were used, not simultaneously.

No alterations were made to the route structure outside the Stockholm terminal airspace to accommodate the RNAV STARs.

4.3 Experimental Factors

To make a validated comparison between conventional and time based operations, the following conditions were compared:

- Baseline condition, a reference reflecting present day operations (2010)
- Time Based CDA concept applying P-RNAV based arrival routes
- Time based CDA concept with shorter RNP based arrival routes

The time based concept with the CTA control waypoint at 30NM (for all arrival directions) were supported by an enhanced AMAN that provided arrival sequence information, target times over different waypoints and time to lose or gain. Controllers were instructed that conventional air traffic control using vector and speed instructions was always allowed when deemed necessary.

The following factors were randomised over the different validation runs

- Traffic sample
- Wind condition
- Controller seating

The simulated traffic scenarios consisted of both inbound and outbound traffic for Arlanda including short flights, flights to/from nearby Bromma Stockholm airport as well as overflying en-route traffic. The amount of traffic into Arlanda was set for a medium-high landing rate.

4.4 Measurements

Fuel consumption, track miles and the number of successful CDA's were derived after the trials on the basis of automatically logged data. In addition, during and after each run subjective feedback was obtained through Instantaneous Self Assessments (of workload), questionnaires and debriefings. As part of the observations the number of coordinations between controllers was also recorded. Following each run direct feedback and comments were given by the participating controllers and pilots.

5 Results

The results covering efficiency and environmental impact as well as operability are described in the next.

5.1 Efficiency and Environmental Impact

5.1.1 Continuous Descent Arrival profiles flown

An important indicator of the feasibility of the developed concept is the number of successfully completed continuous descent profiles under the different conditions during the experiments.

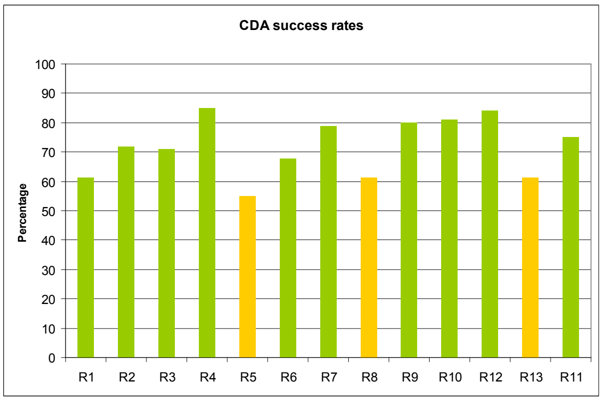

Fig. 6. Comparison of CDA success rates of baseline (yellow) vs time based operations (green)

Fig. 6 provides an overview of successfully completed CDA's from top-of-descent to landing observed during the first week of evaluation sessions (RTS1). Clearly visible is the fact that the time based CDA concept (green) shows a marked improvement compared to the baseline situation situations (yellow). With conventional operations controllers were already achieving successful CDAs in 50 to 60% of the flights.

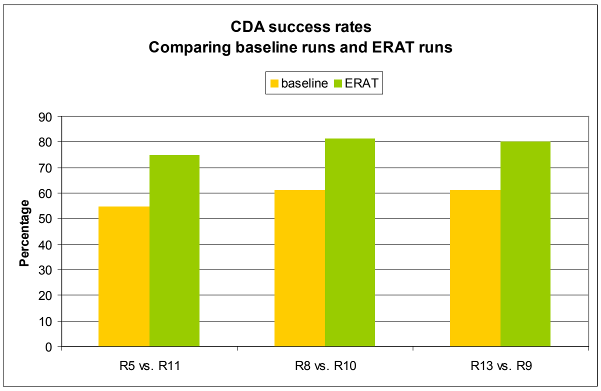

Fig. 7. CDA success rates of baseline (yellow) vs time based operations (green) for comparable runs

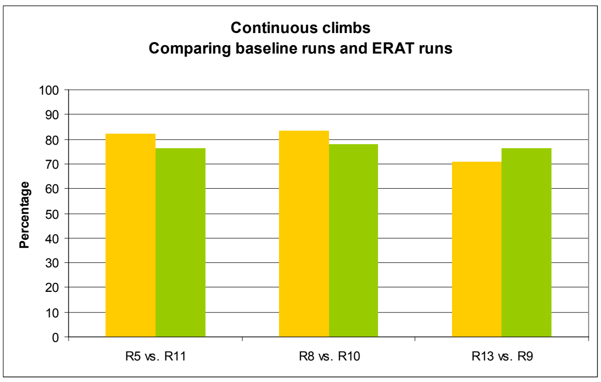

Fig. 8. Percentage continuous climb departures (yellow: baseline; green; time based concept)

Focusing within the overall results on true comparable runs with identical initial conditions in traffic and weather, the figures 6 and 7 show a clear increase in the amount of CDA's without significantly impacting the efficiency of aircraft departures which is shown in figure 8.

5.1.2 Fuel Consumption

Unfortunately the use of P-RNAV routes did not show the expected decrease in fuel use in comparison to the runs with baseline operation. Further analysis of the paths flown showed that the actual flown tracks in the TMA during the baseline conditions were often shorter than the P-RNAV routes flown with the time based concept. As a consequence the shorter RNP routes were developed to assess if these would reduce the fuel use. Although with a limited number of validation runs, trials with RNP arrivals yielded an increase in efficiency in terms of fuel consumption compared to the (longer) P-RNAV arrivals. Despite the fact that the number of successful CDAs was lower with RNP routes compared to standard P-RNAV routes, the fuel efficiency increased by 3%. The approach controllers commented that with the RNP routes fewer possibilities existed to vector aircraft when necessary to maintain separation on final. Apparently, the short routes allow less flexibility: where the P-RNAV routes allow shortcuts and speed instructions, the RNP routes only allow for vectored paths with more track miles. Nevertheless, given the limited familiarisation, the results are promising and the concept with shorter RNP routes is considered feasible in low-medium traffic density.

5.2 Operability

5.2.1 Workload and Situation Awareness

While the definite increase in the amount of successful CDA profiles could be noted, the delegation of 4D trajectory control to arriving aircraft to achieve the target time did not appear to negatively affect controller workload. During the simulations, through a pop-up menu on a separate touch screen, controllers were asked every few minutes to give a self-assessment of their current workload. Averaged results are indicated in Fig. 9 for the approach controllers. The comparison does not show significant differences with the baseline situation. Similar results were also obtained from the en-route controllers.

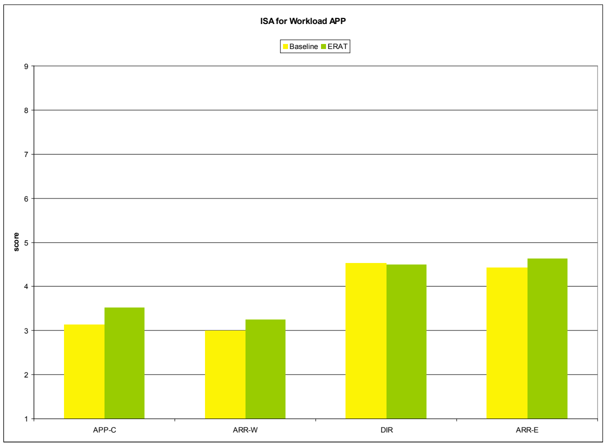

Fig. 9. Instantaneous Self Assessment of Workload by Approach Controllers

During the post-run questionnaires the ATC controllers were requested to rate several aspects concerning their situation awareness (SA), as described in [9]. The resulting SA scores are shown in Fig. 10, which do not show significant differences compared to the baseline situation (yellow).

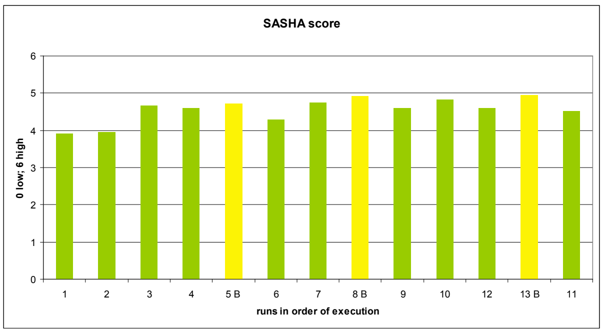

Fig. 10. Average SASHA score for each run (RTS1)

Nevertheless, the participating en-route controllers sometimes noted difficulty to maintain situation awareness on flights that received a CTA time clearance. It was often difficult to estimate the applied FMS speed strategy (i.e. speed up or slow down, descent speed), in particular in relation to surrounding other traffic.

5.2.2 Usability

Controllers rated the usability of the different tools available (AMAN, CTA, sequence number and time to lose/gain) on a seven–point scale. With average scores over 4 these are considered quite positive. As expected, clear differences exist between ratings given by ACC and APP controllers on the usability of the tools. The ACC controllers, who were instructed to provide the CTA clearance to the aircraft, were not so much supported by the sequence number or the time to lose/time to gain. On the other hand, the APP controllers, with the task to merge the streams of traffic for final approach from different directions, were mostly satisfied with the sequence number and the time to lose/gain.

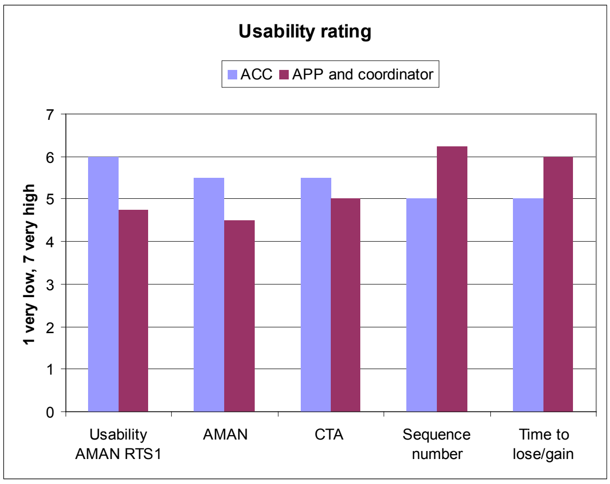

Fig. 11. Usability rating of ATC tools for the time based concept

The experiences gained with the real-time ATC simulations have considerably supported the validation of the time based CDA concept at Stockholm Arlanda and improved the concept as well as supporting technology. Also, improved procedures have been evaluated for adequate handling of so-called “short” flights, with departure times inside the arrival management planning horizon. The knowledge and experience obtained can be applied to other airports to profit from time-based CDAs in daily practice.

6 Discussion and Conclusions

The trials have indicated that the concept of time based CDA approaches is feasible with the offered medium arrival traffic density of 30 to 34 landings per hour on average with temporary traffic peaks. With the time based concept on the standard P-RNAV arrivals, around 20% more CDAs were flown compared to conventional operating procedures in the experiments. Without a significant change in workload, the operational concept and usability of the system tools and HMI were rated positively by the participating controllers [10][11][12].

Although with a limited number of validation runs, trials with RNP arrivals yielded an increase in efficiency in terms of fuel consumption compared to the (longer) P-RNAV arrivals. The number of successful CDAs was lower with RNP routes compared to standard P-RNAV routes, however and controllers mentioned lower flexibility. In hindsight, the amount of dedicated training of the RNP runs should have been more and a definite learning curve was visible during the trials. It is expected that better results are possible with further RNP STAR and SID route refinements as well as more operational experience of both pilots and controllers. Nevertheless, based on simulation results it was expected that a landing throughput of up to 30 aircraft per hour should be feasible when using the drafted RNP STARS, slightly lower compared to the regular P-RNAV STARs.
Given the limited amount of familiarisation with these procedures, the obtained results are promising and the concept with shorter RNP routes is considered feasible in low-medium traffic density.

Apart from evaluating the feasibility of the time based CDA concept, special interest went to developing procedures for better handling of short flights, with flight times of 25-40 minutes, which occur on a regular basis at Arlanda. The short flights are often operated by turboprop aircraft, which also adds an additional challenge in handling within the more homogeneous arrival flow of jet traffic. Since the exact timing of a take-off cannot be performed with the same accuracy as is achieved for time constraints when already in flight, planning the final landing sequence around such a short flight required special coordination. The flights were sequenced in advance using preliminary arrival slots and target take-off times. Although sequencing uncertainty remained until initial climb, the flexibility of the operation proved to be sufficient to deal with short flights and turboprop behaviour.

The experience gained with the real-time ATC simulations have considerably supported the validation of the time based CDA concept at Stockholm Arlanda and improved the concept as well as supporting technology. The knowledge and experience obtained can be applied to other airports to profit from time-based CDAs in daily practice.

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