Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Combining 4D and ASAS for Efficient TMA Operations

Problem area
Environmentally, noise friendly flight operations around airports are currently only possible in periods of low traffic (at night). The reason for this is the lack of good estimations of flight profiles and speeds by the Air Traffic Controller, due to which larger separation minima are to be used between aircraft. Therefore, at high traffic periods, noise friendly Continuous Descent Approaches are not feasible since they would decrease the airport capacity too much.

Description of work
Time-based trajectory-based (4D) operations in the Terminal Area (TMA) around airports have shown to provide good results in terms of efficiency and environment, for one aircraft in isolation. Airborne Separation Assurance System (ASAS) operations have shown to provide the capability to maintain spacing with other aircraft, given that the initial spacing is reasonably well established. In summary, 4D misses the option to control separation / spacing with many aircraft in an area. ASAS on its own misses the possibility to set the initial separation / spacing adequate.

Results and conclusions
This paper describes results of separate 4D and ASAS trials, together with an elaboration of the optimum combination of 4D and ASAS for efficient and environmentally friendly TMA operations.

Applicability
The results are applicable for noise friendly flight operations at airports, at high density traffic periods.

Note
This paper was written and presented by AT-One, the combined NLR and DLR Air Traffic Management alliance.

Report no.
NLR-TP-2007-759

Author(s)
R.C.J. Ruigrok
B. Korn

Report classification
UNCLASSIFIED

Date
October 2007

Knowledge area(s)
Aeronautical Human Factors, Training & Flight Simulation
Flight Operations
ATM & Airport Operation

Descriptor(s)
4D
ASAS
Flight test
Continuous Descent Approach
Terminal Manoeuvring Area

This report is based on a presentation held at the AIAA Aviation Technology, Integration and Operations conference, Belfast, 18-20 September 2007.

Nationaal Lucht- en Ruimtevaartlaboratorium, National Aerospace Laboratory NLR

Anthony Fokkerweg 2, 1059 CM Amsterdam,
P.O. Box 90502, 1006 BM Amsterdam, The Netherlands
Telephone +31 20 511 31 13, Fax +31 20 511 32 10, Web site: www.nlr.nl

NLR-TP-2007-759

Combining 4D and ASAS for Efficient TMA Operations

R.C.J. Ruigrok and B. Korn[1]

[1] German Aerospace Laboratory DLR

This report is based on a presentation held at the AIAA Aviation Technology, Integration and Operations conference, Belfast, 18-20 September 2007.

Customer	AT-One
Contract number	----
Owner	National Aerospace Laboratory NLR
Division	Air Transport
Distribution	Unlimited
Classification of title	Unclassified
	October 2007

Approved by:

Author	Reviewer	Managing department
	B. Korn.	

Summary

Time-based trajectory-based (4D) operations in the Terminal Area (TMA) around airports have shown to provide good results in terms of efficiency and environment, for one aircraft in isolation. Airborne Separation Assurance System (ASAS) operations have shown to provide the capability to maintain spacing with other aircraft, given that the initial spacing is reasonably well established. In summary, 4D misses the option to control separation / spacing with many aircraft in an area. ASAS on its own misses the possibility to set the initial separation / spacing adequate. This paper describes results of separate 4D and ASAS trials, together with an elaboration of the optimum combination of 4D and ASAS for efficient and environmentally friendly TMA operations.

Contents

1 Introduction

Strategic Studies of the future Air Transport System – as the European “Vision 2020” – clearly state that there is a need to further integrate airborne and ground functions in order to cope with the increasing requirements regarding safety and capacity. The common reason for today’s operation is to provide more or less the same level of service to any aircraft regardless of its capabilities and equipment. Thus, development and integration of new systems and functions into the aircraft will not directly result into a more efficient Air Transport System. In order to provide a response to the present airport capacity and future environmental constraints, additional procedures and operational concepts as well as technology and systems need to be developed and implemented. These are required to better use available capacity and to provide additional capacity and efficiency while minimizing the environmental impact of airport operations and maintaining or even improving today’s safety level. Here, major benefits can be expected especially in areas with a high density of traffic like the TMA. Today, the air traffic in TMA is controlled by Air Traffic Control (ATC) mainly with the help of radar vectoring which results in a high workload of the controllers and does not allow efficient aircraft trajectories. Based on the exchange of information between aircraft and ATC via data link, a trajectory based traffic management can take into account user preferred trajectories as well as use highly accurate predication of aircraft movements. The later is important especially in the case of continuous descent approach (CDA) procedures. CDAs are very promising in terms of efficiency and noise reduction but since they do not allow for ATC interference (and predictability of aircraft movement is reduced), it is hard to apply them in high density traffic situation. Therefore, an early coordination between ATC and aircraft is required. Provided that the aircraft is equipped with a 4D capable Flight Management System (FMS), the aircraft preferred 4D trajectory down to the threshold can be computed and linked down to the respective ATC tools. But even in this 4D world, there is still the need to guarantee separation between aircraft. Here ASAS can play an important role. For an optimized use of TMA and runway capacity, the optimum relative separation of aircraft is important. During a fully 4D based approach, disturbances cannot be compensated in an efficient manner, since controllers cannot easily take over. This paper will elaborate how the two concepts, 4D and ASAS, can complement each other, especially in the TMA in high density traffic situations. 4D constraints given to the aircraft by Arrival Management (AMAN) tools on the ground will set the frame for the arriving traffic. Together with an adequate planning, this will guarantee for a smooth traffic flow into the TMA and in particular, towards merging points of two or more arrival streams. To decrease workload of the air traffic controller in situations when conflicts might occur, ASAS applications will help the controller to solve conflicts by giving respective commands on a higher level to flight crew and thus distributing the workload between controller and flight crew.

II Time-based trajectory management (4D)

A. Introduction

In order to meet the anticipated future demand for air travel, Distributed Air-Ground Traffic Management (DAG-TM) concepts for arrivals in the Extended TMA and TMA are studied. Based on the exchange of information between aircraft and ATC via data link, a trajectory based traffic management can take into account user preferred trajectories as well as make use of highly accurate prediction of aircraft movements.

In the aircraft, a 4D Flight Management System (FMS) is required for these types of operations. With a 4D FMS, various approach profiles can be computed and controlled, ranging from 2 degree (clean configuration) up to steep slopes (more than 5 degree) with early configuration and glide path intersection from above. The new CDA functionalities have been implemented in DLR's 4D capable Advanced Flight Management System (AFMS) and intensively tested during various flight trials in the A330 Full Flight Simulator in Berlin and with DLR's test aircraft ATTAS, a VFW 614 twin engine jet transport aircraft modified for research purposes. The results of these trials will be presented and discussed in this section.

Trajectory Based Arrival Management

Figure 1 shows the present situation concerning the air ground communication if an AMAN is used by the controller, e.g. the 4D Planner [1] at Frankfurt Airport.

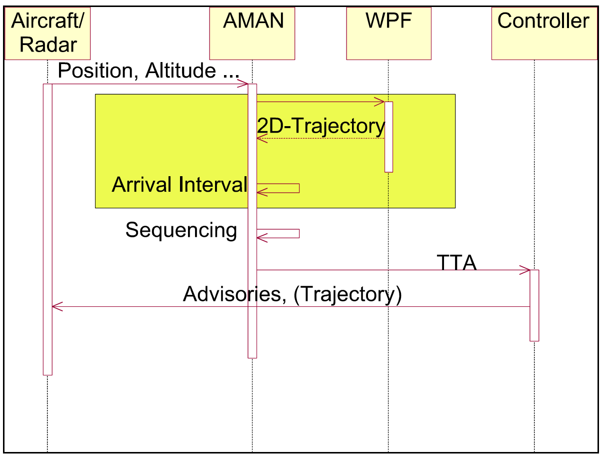

Figure 1: Present Air Ground Communication.

The radar units collect the aircraft positions, the transponders transmit the corresponding altitudes. The update rate is approximately every five seconds. Track information, horizontal and vertical speeds are derived and serve as primary input source for the arrival manager to derive a picture of the current traffic situation. Horizontal 2D profiles are predicted for each arriving aircraft by a module called waypoint finder (WPF), i.e. which route the aircraft may take from its present position to the runway threshold. The AMAN uses this to predict the earliest time of arrival for each aircraft in order to optimize the arrival sequence. Using the separation minima the AMAN assigns a runway and a target time of arrival (TTA) to each aircraft being displayed to the controller by a time scale. It is the controller's task to implement this sequence (or another one) with the assigned target times by adequate advisories via voice control.

The colored part of Figure 1 is the starting point to enhance air ground cooperation with data link. Within the C-ATM concept [2] it is designed that the planning computers on ground directly interact with the on board FMS. On board generated flight profiles are transferred to the ground systems via data link to incorporate them into a sector overall traffic planning. Flight plan conflicts are early detected. A negotiation process between aircraft and service provider is conceivable to get an optimal flight profile considering all present aircraft and ground constraints.

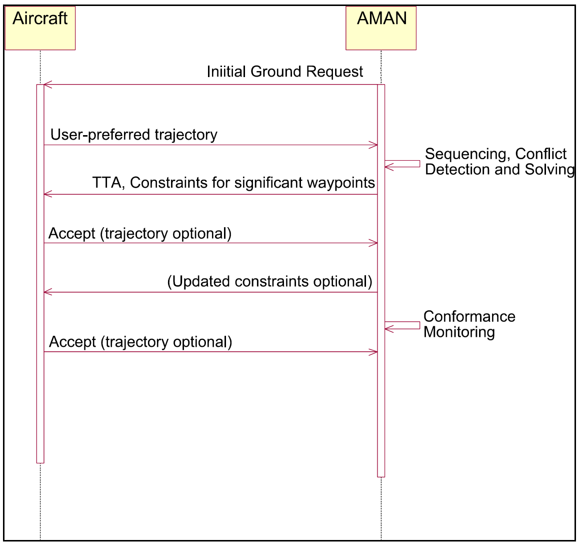

Figure 2: Air Ground Cooperation.

The air ground cooperation is initiated after radar contract by the AMAN. After the Initial Ground Request (Figure 2) the on board FMS sends its flight intent (user-preferred trajectory) to the ground. The level of detail highly depends on the data link capacity.
During phases of high traffic demand the AMAN will normally not accept the exact user preferred trajectory due to conflicts with other aircraft. It is, however, possible to use the aircraft's target time for an update of the earliest time of arrival and the AMAN can extract parameters from the user preferred trajectory (e.g. descent rates, speeds) to trigger the ground trajectory generation process, after having updated the arrival sequence.

The ground generated conflict free trajectory is used to generate both advisories for unequipped aircraft for voice communication and to calculate appropriate ground constraints for the on board FMS for voice or data link communication.
Using the ground ATC constraints, the on board FMS is generating a new trajectory. Depending again on the available data link capacity the new on board trajectory is transmitted to the ground (accepted trajectory in Figure 2) and can replace the ground trajectory for detecting future planning conflicts and is used for conformance monitoring.
In both cases the FMS or the pilot have to send an acceptance message and the ground has to answer with a clearance if the accepted trajectory sufficiently meets all ground constraints. Then the pilot is allowed to activate the trajectory, which is transferred to the ground. If a ground update of the arrival sequence or an on board correction of the cleared trajectory is necessary, a new air-ground negotiation cycle is started.
This concept is open for integrating complex approach procedures like Advanced CDA (ACDA) even in high density traffic situation. For ACDA to be carried out efficiently, the vertical profile will be specific and won't be easily modifiable. Also, the lateral path has to be kept constant in order to guarantee a constant length. For those reasons, it is important to have a smooth flow of arriving traffic as there are fewer options for the controller to control the arrival sequence without too much interference. This requires an early planning of the arrival traffic and the early and reliable co-ordination of expected/required arrival times between arriving aircraft and ATC (particularly with the AMAN). Both requirements are fulfilled with the presented concept and tools (AMAN, FMS). The already very precise trajectory prediction capability of the AMAN allows for an optimized traffic flow in the (extended) TMA. The subsequent refinement of the trajectories by FMS-AMAN coordination and the capability of the FMS to exactly fly the trajectory ensure as well the implementation of the planned traffic flow. More information about the concept and the ground (AMAN) functions can be found in [3].

For the onboard part, the strategic trajectory generation as well as the automatic guidance along this trajectory according to schedule is the domain of the Flight Management System (FMS). As today's FMS suffer from the poor interfacing with the aircrew and ATC an Advanced Flight Management System (AFMS) is being developed by DLR based on the Experimental FMS developed within the Programme for Harmonized Air traffic management Research in Eurocontrol (PHARE), see [4], [5] and [6].

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

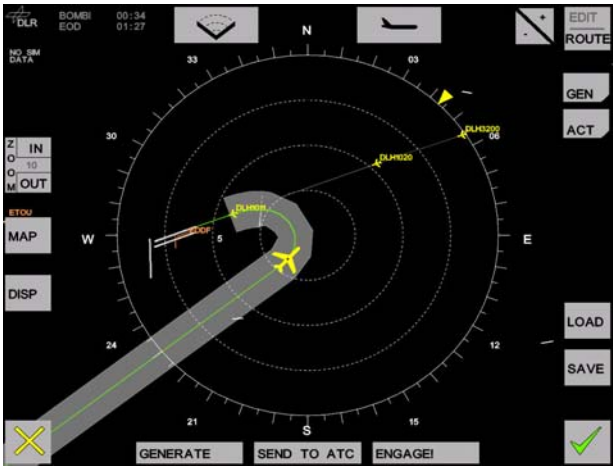

Figure 3: Navigation Display as interface to the AFMS during a continuous descent approach.

The main features of the AFMS are:

- Computation of 4D-trajectories on board considering constraints received via data link from ATC, aircraft performance parameters, meteorological conditions, economical criteria, etc.
- Negotiation of the flight plan with ATC/ATM by means of data link connection, and
- 4D-guidance capabilities along the engaged negotiated trajectory.

Advanced Continuous Descent Approach (ACDA)

An advanced continuous descent approach is basically an approach, where straight and curved segments are integrated in the descent profile which starts at the TOD (top of descent) of the enroute phase or at the TMA entry altitude. Thus the level flight at intercept altitude can be minimized so that the environmental impact is reduced, see Figure 4. A good definition of an ACDA can be found in [7]: “An ACDA allows the aircraft, after passing the Initial Approach Fix, to start a continuous descent to the runway threshold along a curved, earth referenced, approach path with both lateral and vertical guidance.”

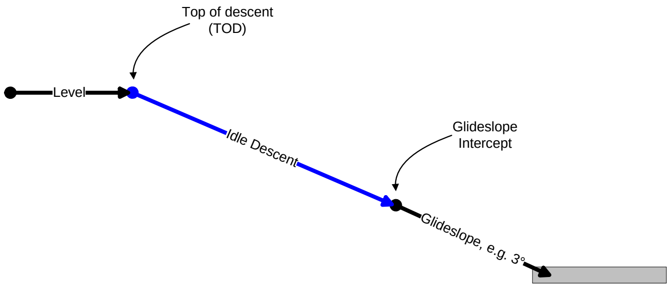

Figure 4: Generic vertical profile of an ACDA.

With respect to the concept of trajectory based traffic management in the TMA, a very important task of the FMS is to plan the trajectory and later on guide the aircraft during the ACDA such that it will meet all time constraints given by ATC. A full 4D guidance during ACDA is therefore required. The FMS has to calculate the exact TOD taking into account the actual weather (wind) situation (and its forecast) and the aircraft's performance data.

The AFMS performs a backward calculation of the TOD starting with the glide slope intercept point such that an idle descent under the actual know weather conditions from TOD will intercept the glide path at the predefined position. This glide slop intercept point is determined by the ILS glide slope and the desired intercept altitude. The foreseen speeds during the different approach phases depend on aircraft's configuration and respective performance data. Thus, the exact timing for the configuration change points and the duration of such a configuration change has to be taken into account in the trajectory calculation. Otherwise, this would lead to deviation in time which might not be acceptable in the frame of a (4D) trajectory based traffic management. Figure 5 shows such an ACDA for an Airbus A330-300. In Figure 6 an ACDA profile of our test aircraft ATTAS, a VFW 614, is depicted. Due to different performance, the idle descent phase is much shorter and steeper.

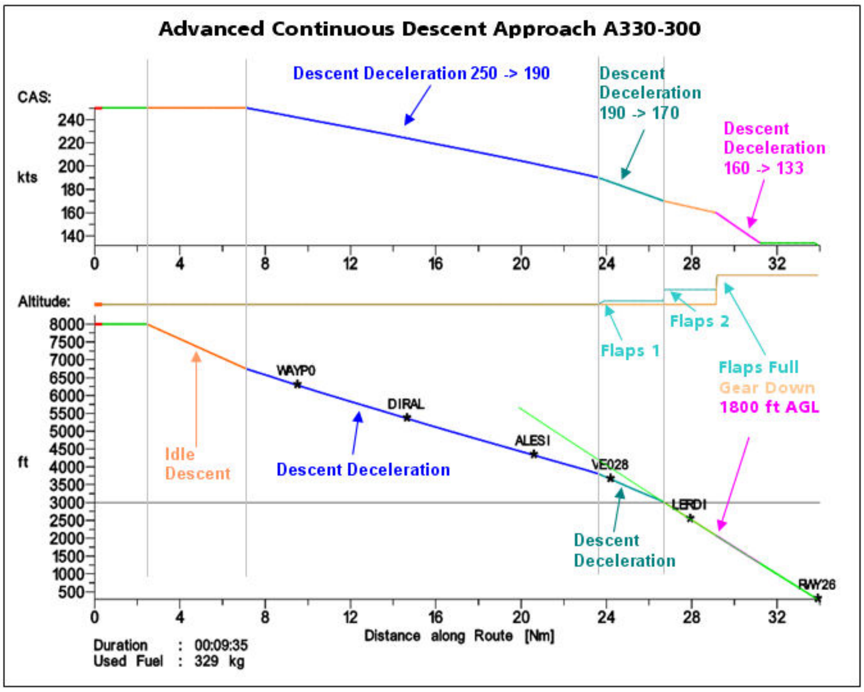

Figure 5: ACDA for an Airbus A330-300.

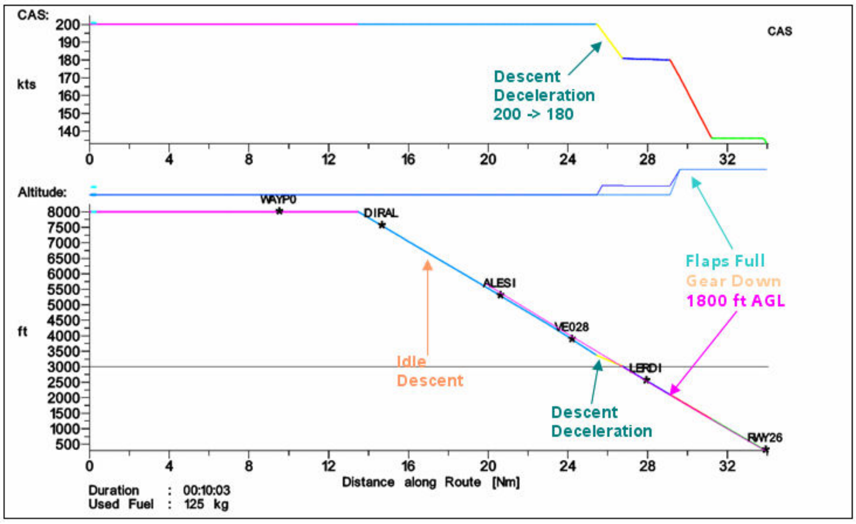

Figure 6: ACDA for the ATTAS VFW614 aircraft.

During the execution of an ACDA, deviation of the planned trajectory will occur if among others the performance data and/or the weather forecast are not exact enough. Therefore, during execution some means for compensating these inaccuracies have to be implemented. In our AFMS we use an earlier setting of the flaps 2 configuration to mitigate a positive altitude error. A negative altitude error is compensated by an introduction of a less steep (in extreme cases of a level) segment and in addition of a small thrust increase to still meet the time constraint at the intercept altitude.

Results from simulation and flight trials

The ACDA functionalities of the AFMS have been intensively tested during various flight trials in the A330 Full Flight Simulator in Berlin (Figure 7) and with DLR's test aircraft ATTAS (Figure 8).

Figure 7: A330 full flight simulator in Berlin.

Figure 8: DLR ATTAS VFW614 test aircraft.

In Figure 9 a typical result of an ACDA approach with the A330 simulator in Berlin is depicted. The ACDA started at a TOD at flight level 110 and ended at a glide slope intercept altitude of 4000 ft. During the approach the altitude error remained in the interval of +30 ft/ - 120 ft. which is fully acceptable for this application. The error in time remained below 1 second until the intercept altitude and did not exceed 3 seconds at touch down which is as well a very good result.

Figure 10 shows a typical result of a flight trial with the ATTAS aircraft. Here it was an ACDA to Braunschweig airport starting at 7000 ft with an intercept altitude of 3000 ft. Except during configuration changes the altitude error remained smaller than 50ft. Again – although having real flights in real weather conditions – the error in time remained in the same interval of ± 3 seconds which clearly demonstrate the good performance of the implemented FMS modules.

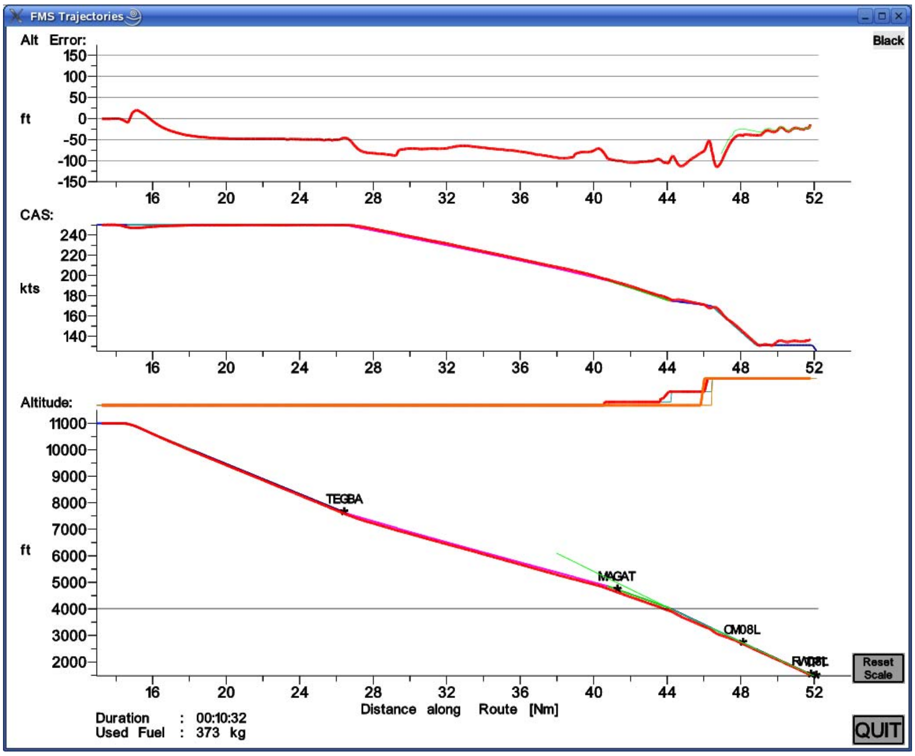

Figure 9: Results of an ACDA with the A330-300 simulator in Berlin.

Figure 10: Results of an ACDA flight trial with DLR's test aircraft ATTAS.

III Airborne Separation Assistance System (ASAS) operations

A Introduction

The Automatic Dependent Surveillance – Broadcast (ADS-B) system allows a digital data link between aircraft and between air and ground. The Airborne Separation Assistance System (ASAS) on board of aircraft accommodates ASAS application. ASAS applications range from ASAS Awareness, ASAS Spacing, ASAS Separation to ASAS Self-Separation category applications, see [8] and [9].

For TMA operations, the ASAS Spacing applications are most applicable. ASAS Spacing in general involves the delegation to the pilot of certain spacing and positioning tasks in relation to a specified target aircraft. The pilot takes responsibility for identifying the target aircraft and establishing separation based on instructions from the ground. Whilst relieving the controller of several routine tasks, the controller remains responsible for ensuring standard separation.
In more detail, the enhanced sequencing and merging operations (ASPA-S&M, see [9]) are very relevant for TMA operations. The objective is to redistribute tasks related to sequencing (e.g. in-trail following) and merging of traffic between the controllers and the flight crews. The controllers will utilize a new set of instructions allowing them, for example, to instruct the flight crews to establish and to maintain a given time or distance in trail from a designated aircraft. The flight crews will perform these new tasks using a suitable human-machine interface. One anticipated benefit is increased capacity through better adherence to the ATC-requested spacing.

NLR and/or DLR are and have been involved in several projects in which these applications are or have been tested in ATC simulation, flight simulation and flight trials, such as MFF, MA-AFAS, DAG-TM, G2G, FLYSAFE and OPTIMAL. In March 2006, a time-based ASAS ASPA-Sequencing & Merging application has been flight tested by NLR, using both NLR laboratory aircraft. This section will report on these trials.

B. Aircraft

NLR operated their Cessna Citation II and Fairchild Metro II aircraft, registered as PH-LAB and PH-NLZ, in the ASAS trials performed at Groningen airport, in the north of the Netherlands. Originally a business jet, the Citation II has been extensively modified to serve as a versatile airborne research platform. A twin-engine propeller aircraft, the Metro has been similarly adapted and is very suitable for airborne research.
Both PH-LAB and PH-NLZ are registered under a Restricted Type Certificate, enabling integration of experimental hardware for research purposes. Measurement and data communication facilities are available. Both aircraft provide an opportunity to develop, integrate and evaluate hardware in a real aircraft environment.

The Citation-II, see Figure 11, is a twin engine turbofan aircraft with a Maximum Take-Off Weight (MTOW) of 14100 lbs. in the transport category. The Citation could operate in the restricted category when the MTOW for the transport category is exceeded. MTOW in the restricted category is 14600 lbs. Maximum operating speed is 262 KIAS below 30500 ft. Above 30500 ft, the maximum operating Mach number is 0.705. Maximum operating altitude is 43000 ft. The Fairchild Metro II, see Figure 12, is a twin-engine propeller aircraft with a Maximum Take-Off Weight (MTOW) of 12500 lbs, maximum operating speed is 248 KIAS and maximum operating altitude is 25000 ft.

Figure 11: NLR Cessna Citation II laboratory aircraft.

Figure 12: NLR Fairchild Metro II laboratory.

The ASAS equipment/functions are integrated in both aircraft. ADS-B data, received by the VDL Mode 4 transponder, is fed into the experimental displays (PFD and ND) which are shown on an LCD cockpit display. The ASAS functionality is integrated in the Research Flight Management System (RFMS), which can be operated by a “soft” CDU. This “soft” CDU is a software version of a real CDU, which will also be shown on the pilot displays. The pilots can select the CDU by operating the buttons below the PFD. The CDU will temporarily be overlaid over the PFD and can be de-selected again by the pilot, to show the PFD again. Figure 13 and

Figure 14 below show these two configurations. The CDU and other features are operated with a tracker-ball mounted on the armrest of the seat of the right seated pilot.

Figure 13: Standard display layout.

Figure 14: Display layout with temporary CDU.

C ASAS Sequencing & Merging functions

The ASAS Spacing functions have been implemented in the Research Flight Management System. The indications to the pilot are shown on the Primary Flight Display (PFD) and the Navigation Display (ND). Figure 15 and Figure 16 show the cockpit displays with ASAS Spacing symbology.

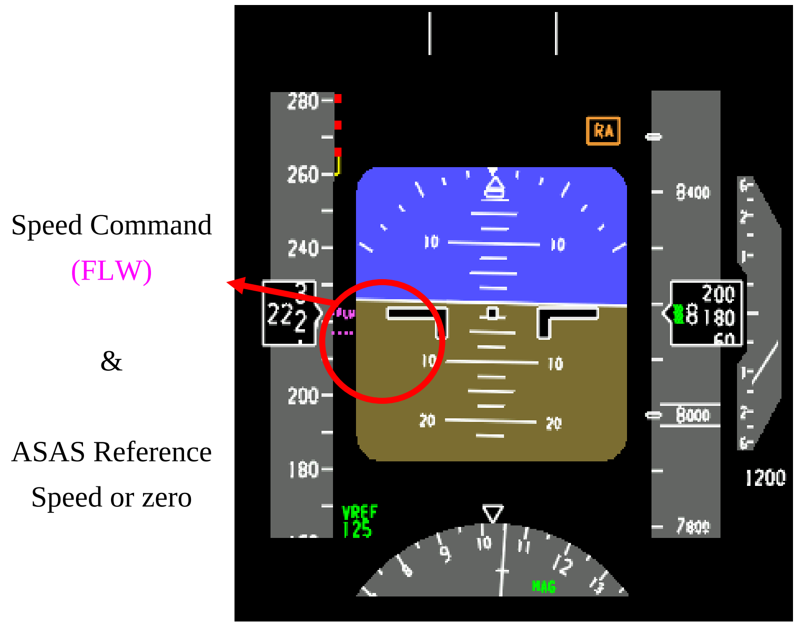

Figure 15: PFD with ASAS Spacing symbology.

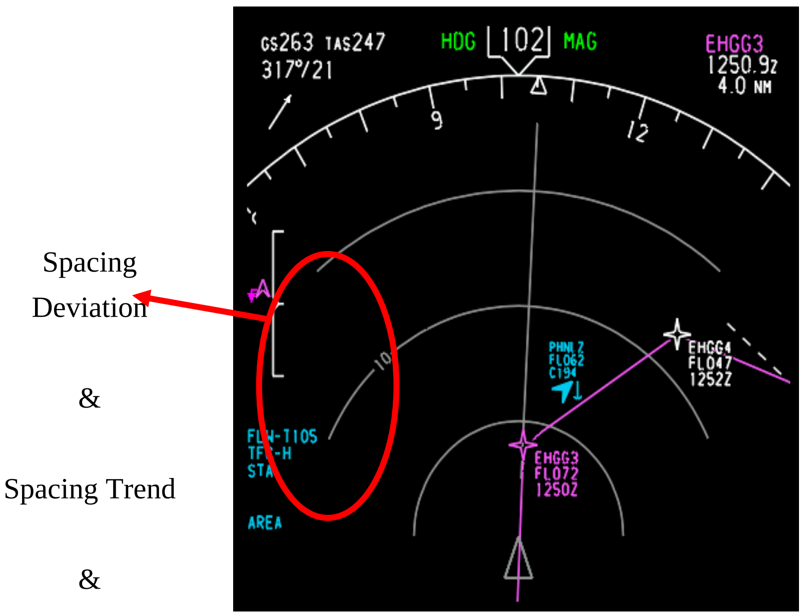

Figure 16: ND with ASAS Spacing symbology.

The main parameters presented to the flight crew are:

- ASAS Speed Command (to reduce/increase spacing)
- ASAS Reference Speed, zero closure rate speed (to maintain spacing)
- Spacing Deviation
- Spacing trend vector, change in one minute

D. Flight trials

In March 2006, both NLR laboratory aircraft were flown to Groningen Airport for a two day flight trials program to test the ASAS Sequencing & Merging application during a Continuous Descent Approach. In order to have "control space" for the speed during the CDA, it was chosen to fly the descent using a 2 – 2.5 degrees descent path. Figure 17 depicts the chosen descent path in red, as also considered in the SOURDINE 2 [10] and OPTIMAL projects [11].

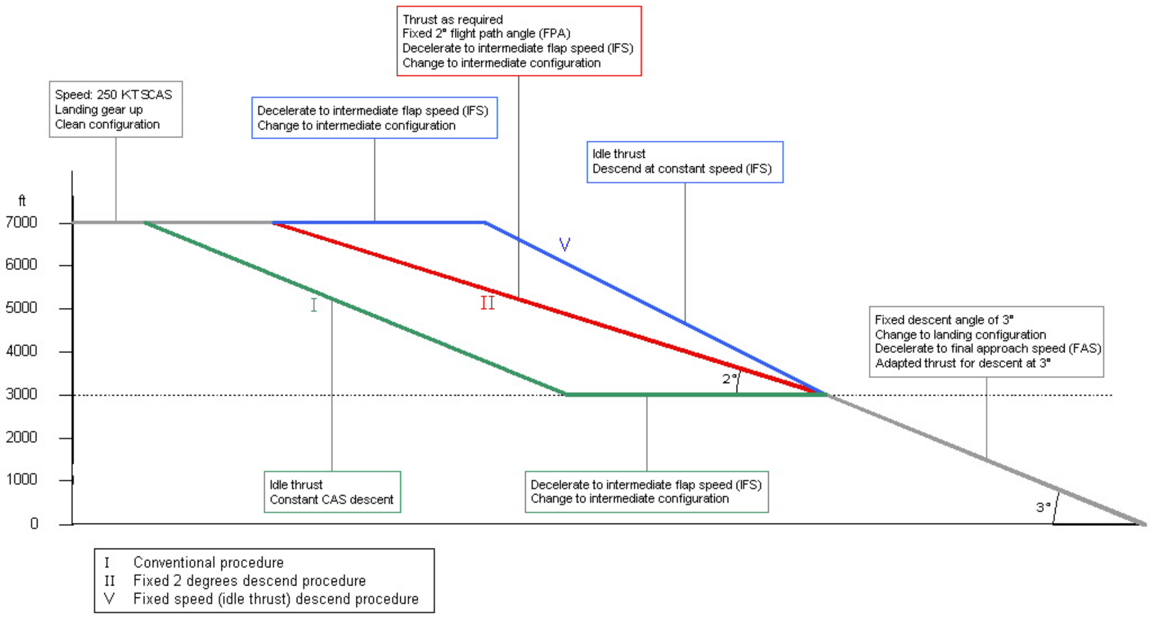

Figure 17: Conventional, Idle and 2 degree decent approaches.

A non-existing approach (see Figure 18) was developed and flown 10 times from FL090, during regular traffic at the airport and using the ASAS instructions by the controllers in a real-life R/T environment.

Figure 18: Approach flown at Groningen Airport.

The controller and crew ASAS instruction and communication, using R/T, was as follows:

EVENT	EELDE APPROACH CONTROLLER	AIRCREW PH-LAB	AIRCREW PH-NLZ
DURING VECTORING	PAB, TARGET PHNLZ PAB, TARGET CORRECT	TARGET PHNLZ, PAB PAB, TARGET PHNLZ, 11 O'CLOCK, 9 MILES, 1000 ABOVE	
PH-NLZ BETWEEN POINT #1 AND #2	PLZ, CLEARED FOR EELDE ONE APPROACH RWY 23 *		CLEARED FOR EELDE ONE APPROACH RWY 23, PLZ
PH-LAB AT POINT #1 (INBOUND POINT #2)	PAB, BEHIND TARGET, REMAIN 105 SECONDS BEHIND	BEHIND TARGET REMAIN 105 SECONDS BEHIND, PAB	
PH-LAB BETWEEN POINT #1 AND #2	PAB, CLEARED FOR EELDE ONE APPROACH RWY 23 *	CLEARED FOR EELDE ONE APPROACH RWY 23, PAB	

* The instruction implies clearance to fly the (experimental) approach, vertical profile and ILS approach to RWY 23. A continuous descent will be flown so as to reach the FAF at 2000'.

E. Analysis and results

Main focus during the analysis was the adherence to the time-based required spacing. Figure 19 shows the results for the various waypoints along the approach. The required spacing was in all 10 runs set at 105 seconds. As can be seen from the figure, the required spacing is accurately met, with standard deviations in the order of 2 seconds.

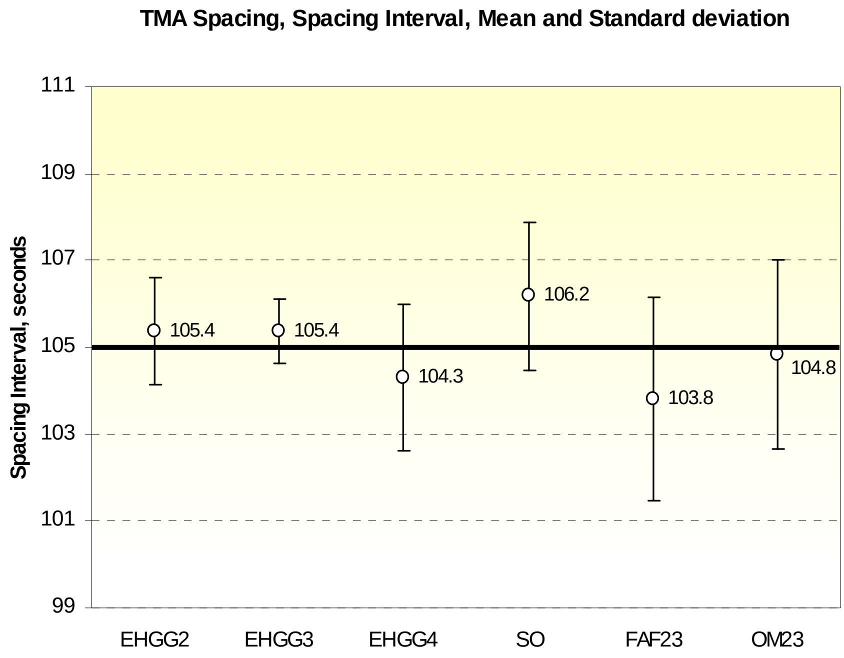

Figure 19: Relative spacing (in time) over waypoints.

Figure 20 shows a track of one of the 10 runs. As can be seen from the dark blue line, a Continuous Descent Approach was indeed performed. The relative distance (separation/spacing) between the two aircraft is shown in bright blue. This shows the advantage of time-based spacing. At FL090 the spacing in distance is roughly 8 nm. At the Outer Marker this has reduced to 4 nm due to the lower speed of both aircraft. The time-based separation remained at 105 seconds at all waypoints along the approach, as the previous figure has shown. Using this mechanism, a “natural” reduction of the distance between aircraft is established during the descent, without the need for any instructions by the controller.

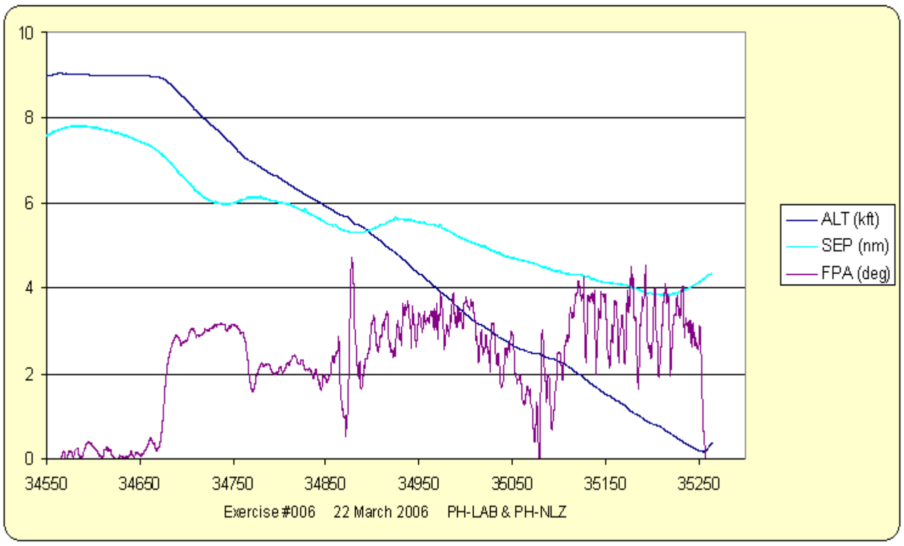

Figure 20: Time trace of one approach.

IV Discussion

The research to both 4D trajectory management and ASAS Spacing has shown that both are capable of meeting seconds accuracy compared to the required spacing in time, or time of arrival over a fix. In this section the most likely and optimum combination of 4D and ASAS is discussed.

4D is strong in meeting the required time of arrival over fixes in the descent. 4D however does not by itself separate / space from other traffic. For this, a ground system is required. In the case all aircraft at a busy airport are on a 4D trajectory towards the airport, constrained by required times over fixes, a small disruption of the situation might require an update of all required times over fixes of all these aircraft. Especially if the controller is / should be involved in these instructions somehow, this seems not feasible, given the large number of required updates. Only a very advanced automated system on ground will be able to handle this, whereby the required robustness of such an approach still needs to be verified.

ASAS is strong in separating / spacing from other traffic in the descent, given that some control space (e.g. 2 deg descent path) is available. ASAS however does not by itself plan that all arriving aircraft at an airport arrive at such times that a smooth merging and sequencing takes place. Therefore, setting up an ASAS sequence of traffic requires quite some time and effort from the controller in this case.

Combining 4D and ASAS should be such that the advantages of both are used and the weaknesses of both are reduced. This means that aircraft should in the future receive a time constraint at e.g. the T/D, since at this point the converging of traffic to an airport starts. A further time constraint could be given at the Initial Approach Fix (IAF) since at this point merging towards a sequence of aircraft for the runway starts. When the aircraft arrive time spaced at the IAF, the merging process is relatively easy. From the IAF to the runway, time in absolute sense, is not the main issue any longer. At this stage the relative spacing in the sequence of aircraft is of most importance in order to assure high runway capacity. ASAS can provide this relative spacing in the sequence from the IAF to the Outer arker (OM) or runway, simplifying the task of the controller. The centralized process of separating an arrival sequence of traffic has become a distributed task over the aircrew and controller during the descent. Following this approach we do not necessarily allow the optimal (e.g idle) continuous descent for each aircraft. But this combination leads to a robust system, which still allows for individual adjustments of each aircraft's profile. One major advantage is that advanced approach procedures like CDAs (the 2° to 2.5° version) can be integrated into high density traffic in the TMA even with today's TMA route structure.

In summary, 4D can be used to establish an accurate initial spacing between aircraft at e.g. the IAF. ASAS can be used to maintain the accurate sequence from the merge point (e.g. IAF) to the Outer Marker.

V Conclusions and recommendations

4D trajectory based operations and ASAS have often been discussed as concepts that exclude each other. In this paper, we have presented an approach that combines the advantages of both approaches to allow efficient operations (like CDAs) even in high density terminal areas. The presented concept for air ground cooperation is based on the exchange of ATC constraints, aircraft onboard trajectory management via data link and Airborne Separation Assistance System (ASAS) applications based on air-air data links. The concept enables time-based, 4D, user preferred trajectories to Top of Descent and Initial Approach Fix, followed by a tight spacing of aircraft from the Initial Approach Fix to the runway, managed by the flight crew using ASAS tools.

The concept offers a good distribution of tasks between ground and airborne systems and a good sharing of task between automated systems and the human operator. Furthermore, a step-by-step introduction of both parts (4D and ASAS) of the concept is possible, using either data link or

R/T initially. This allows for a gradual introduction of this concept, while gaining benefits at each step.

With the (flight) demonstrated 4D and ASAS functions and tools, NLR and DLR, together in AT-One, are ready for the new ATM concepts such as currently developed in SESAR and NextGen.

Abbreviations

ACDA	Advanced Continuous Descent Approach
ADS-B	Automatic Dependent Surveillance – Broadcast
AFMS	Advanced Flight Management System
AMAN	Arrival MANager
ASAS	Airborne Separation Assurance Systems
ATC	Air Traffic Control
ATM	Air Traffic Management
CDA	Continuous Descent Approach
CDTI	Cockpit Display of Traffic Information
CDU	Control & Display Unit
DMAN	Departure MANager
FAF	Final Approach Fix
FL	Flight Level
IAF	Initial Approach Fix
IAS	Indicated Airspeed
LCD	Liquid Crystal Display
LNAV	Lateral Navigation
ND	Navigation Display
NM	Nautical mile
PFD	Primary Flight Display
RFMS	Research Flight Management System
R/T	Radio Telephony
RWY	Runway
TMA	Terminal Manoeuvring Area
TOD	Top of Descent
VNAV	Vertical Navigation
WPT	Waypoint

References

[1] Gerling W., Seidel D. Project 4-D Planner, Institute of Flight Guidance, Scientific Seminar, Braunschweig, Germany, Oct. 2002.

[2] C-ATM consortium: C-ATM Operational Concept Document. Version 1.4. December, 2005.

[3] Korn, B., Helmke, H., Kuenz, A. 4D Trajectory Management in the Extended TMA: Coupling AMAN and 4D FMS for Optimized Approach Trajectories, *Proceedings of the ICAS 2006 conference, Hamburg,Germany 2006*

[4] Adam, V., Teegen, U.: PD/2 Final Report, Annex F: Airborne Aspects of PD/2, EUROCONTROL, DOC 97-10-13, (1997)

[5] Adam, V., Ingle, G., Rawlings, R.: Experimental Flight Management System, AGARD CP 538, Berlin (1993)

[6] Eurocontrol DOC 98-70-18, PHARE Advanced Tools Trajectory Predictor, (see http:// www.eurocontrol.int/phare/gallery/content/public/documents/ 98-70-18-v10_tp.pdf), August 1999

[7] Erkelens, L., “Development of noise abatement procedures in the Netherlands”, NLR-TP-99386, November 1999.

[8] Anon., “Principles of Operation for the use of ASAS”, PO-ASAS, FAA/Eurocontrol Action Plan 1, June 2001.

[9] Anon., “ASAS application maturity assessment”, Version 2.0, 9 March 2007, ASAS-TN2 project
(www.asas-tn.org).

[10] http://www.sourdine.org/

[11] http://www.optimal.isdefe.es/