Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Time-based navigation and ASAS interval managed CDA procedures

Problem area
With the continuing growth of air traffic as well as the ever increasing level of urbanization around most airports in Western Europe, the impact of aircraft noise and emissions on the quality of life for surrounding communities has become a serious issue to be dealt with. Throughout the world, much effort is being undertaken to increase the usage of Continuous Descent Approaches (CDA). This type of operation can provide significant reductions to community nuisance while improving the fuel economy in the approach. There are, however, still many issues to resolve prior to the realization of this type of operation during *high-density* traffic at major airports. Present air traffic control procedures and technology do not easily allow flying such procedures except during night time when there is less traffic. To improve the throughput (for use during daytime) the initiation of a CDA procedure should be better planned and the execution should be more accurate.

Description of work
This report describes the development and validation of operating environmentally efficient Continuous Descent Approach (CDA) procedures in a future high density environment e.g. Amsterdam Airport Schiphol. Efficient CDA operations are promoted by improved planning of traffic flows, before initiating the continuous descent, and time-based navigation or ASAS interval managed CDA procedures to the runway threshold.
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 developed innovative procedures for the approach and landing phases of aircraft and rotorcraft. The

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This report is based on a presentation held at the CEAS conference, Manchester UK, 26-29 October.

project objective was to minimize environmental impact and increase airport capacity while improving operational safety. Part of the validation activities consisted of real-time human-in-the-loop simulation sessions in NLR's moving base full flight simulator GRACE and fixed based simulator APERO, involving airline flight crews.

Results and conclusions
The evaluation showed promising results with respect to the feasibility of ACDA combined with a CTA at threshold or ASAS spacing. Also the use of fixed RNAV STARs containing predefined path stretching doglegs combined with speed control for improved inbound flow control is acceptable from a pilot point of view.

Applicability
The results of this work will be used in the SESAR and CleanSky research initiatives, with the objective to achieve environmentally friendly approach operations during high density periods at major airports in the future European ATM system for 2020 and beyond.

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Contents

TIME-BASED NAVIGATION AND ASAS INTERVAL MANAGED CDA PROCEDURES

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Keywords: *Advanced Continuous Descent Approach, CDA, RTA, RTI, ASAS, flight simulation*

Abstract

This paper describes the development and validation of operating environmentally efficient Continuous Descent Approach (CDA) procedures in a future high density environment e.g. for Amsterdam Airport Schiphol. Efficient CDA operations under high density traffic conditions are promoted by improved planning of traffic flows, before initiating the continuous descent, and time-based navigation or interval managed CDA procedures to the runway threshold.

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Abbreviations

AFL	Above Field Level
ASAS	Airborne Separation Assistance System
ATM	Air Traffic Management
CDA	Continuous Descent Approach
CTA	Controlled Time of Arrival
ETA	Estimated Time of Arrival
ETMA	Extended TMA
FAS	Final Approach Speed
FDMS	Flight Deck Merging and Spacing
FMS	Flight Management System
IAF	Initial Approach Fix
MCDU	Multi-purpose Control & Display Unit
ND	Navigation Display
OPTIMAL	Optimised Procedures and Techniques for Improvement of Approach and Landing
PFD	Primary Flight Display
RNAV	Area Navigation
RTA	Required Time of Arrival
RTI	Required Time Interval
STAR	Standard Arrival Route
T/D	Top of Descent
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 noise significantly decreases noise exposure around airports. Comparative studies [2] indicate possible noise reduction from 3dB to 8dB compared to conventional operations, including reduced fuel consumption and particle emissions in the terminal airspace.

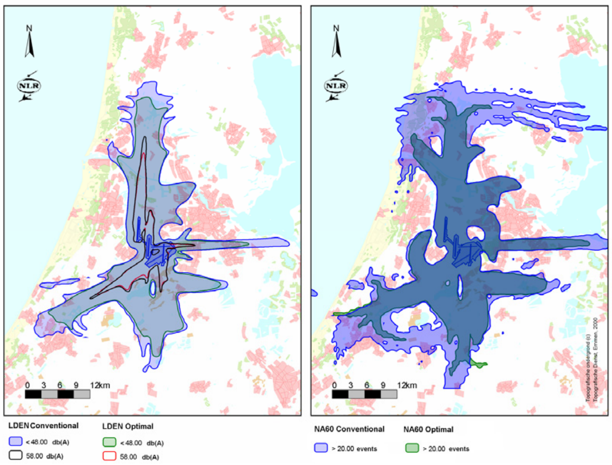

Figure 1: Noise impact at Schiphol airport, comparison of conventional and CDA ops.

There are, however, still many issues to resolve prior to the realisation of this type of operation during *high-density* traffic at major airports. Present air traffic control procedures and technology do not easily allow flying such procedures except during night time when there is less traffic.

The aim of the presented study, carried out within the OPTIMAL project [1], was to investigate the feasibility and pilot acceptability using RNAV STARs containing path stretching techniques, called doglegs, combined with speed control for improved inbound flow control, and use of time-based navigated or ASAS interval managed CDA procedures in the TMA.

The study was conducted for the Amsterdam Schiphol case, but the underlying concept is also applicable for other airport environments.

2 CDA procedure and operational concept

The following paragraphs give an overview of the applied CDA procedure within their operational context. Furthermore, ATM integration aspects and enabling technologies are discussed.

2.1 Descent profile definition

Continuing on the experiences obtained from earlier projects (most notably Sourdine II [3]), two CDA descent profiles were considered within the OPTIMAL project. The so-called *optimised* CDA offers most noise reduction with a fully idle descent, however presently at a loss of capacity. A *nominal* CDA requires thrust to fly the less steep, fixed vertical path (see also Figure 2). Consequently, aircraft spacing corrections can be performed by thrust adjustments. The *nominal* CDA makes the vertical path and aircraft spacing more predictable and repeatable, easing the controller's task to monitor and separate traffic.

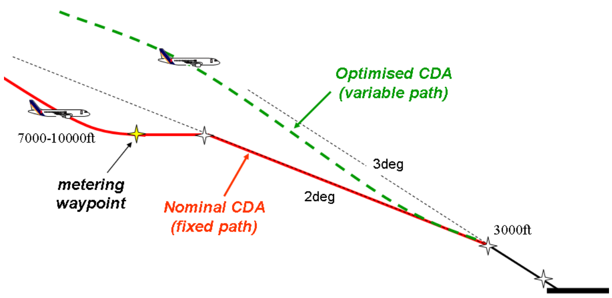

Figure 2: Nominal/Optimised CDA profiles

Therefore, the current 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 airside and groundside capabilities, thus facilitating an easier integration in the medium term. In this study with a focus on TMA operations the CDA nominal descent profile to the runway starts at 7000ft.

To improve runway capacity while using CDA procedures, time-based navigation through

To improve runway capacity while using CDA procedures, time-based navigation through advanced *thrust* policies or ASAS interval managed spacing through advanced *speed* policies may be used as means to realise a highly accurate aircraft spacing method. Both variants are discussed in the following sections.

2.2 Time-based navigation CDA procedure

In a time-based navigation CDA procedure a *Required Time of Arrival* (RTA) is defined at the runway threshold. This RTA should be issued as soon as possible but at last at initiation of the CDA procedure.

Two different speed profiles were investigated for executing this type of CDA: a stepwise speed profile - *idle thrust* policy - and a continuous decreasing speed profile - *constant thrust* policy -.

The *idle thrust* policy accomplishes an RTA at threshold constraint by calculating the appropriate (relatively small) thrust settings at the deceleration segments before an upcoming speed constraint. See also Figure 3. The yellow circles represent speed constraints, and the green circles represent configuration change points. The configuration speeds are chosen static (10 knots above minimum manoeuvring speeds).

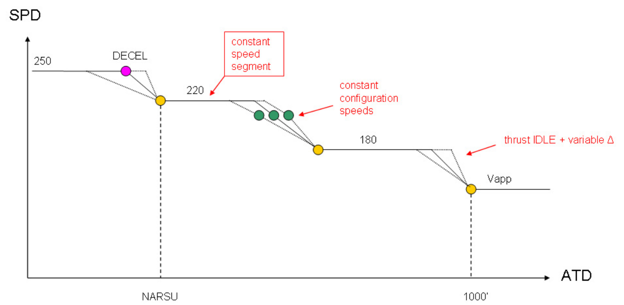

Figure 3: Stepwise speed profile using idle thrust policy

The *constant thrust* policy attempts to accomplish an RTA at threshold by adjusting the configuration speeds. Consequently, the configuration speeds are dynamic (around 10 knots above minimum manoeuvring speeds). At the various segments in between speed constraints, thrust settings are kept constant. The applied thrust is calculated such that the speed is continuous decreasing in between the speed constraints. See also Figure 4.

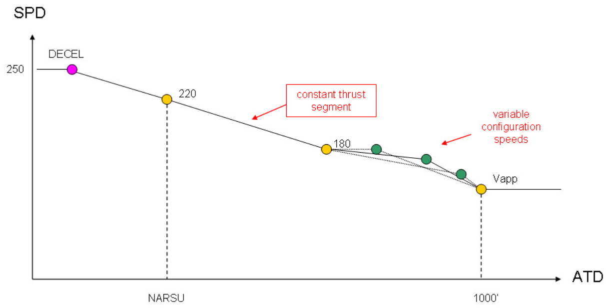

Figure 4: Continuous decreasing speed profile using constant thrust policy

To enable high runway capacity levels, a threshold timing accuracy of within ±5 sec is desired.

Note that the nominal speed profile using constant thrust policy lies exactly in between the resulting speed profiles of the two extreme cases using idle thrust policies: very early (reducing as early as possible to the speed of the upcoming speed constraint) and very late (reducing as late as possible to the speed of the upcoming speed constraint) as described above. Consequently, in case a time constraint at runway threshold is compensated for by thrust adjustment instead of configuration speed adjustments, the nominal speed profile based upon a constant thrust policy provides the maximum control space for compensation.

2.3 ASAS interval managed CDA procedure

In an ASAS interval managed CDA procedure a *Required Time Interval* (RTI) is defined with respect to the lead aircraft. Similar to time-based navigation, the RTI together with lead aircraft identification should be issued as soon as possible but at last at initiation of the CDA procedure, approx 40-50 tracks miles to the runway threshold.

The ASAS speed command is calculated such that the RTI with the lead aircraft is accomplished. This functionality is also called *Flight Deck Merging and Spacing* (FDMS) [4]. The magnitude of the corrections to the nominal speed profile is determined by the magnitude of the spacing error and the along track distance (ATD) to the runway threshold. These speed corrections will be more aggressive closer to the runway threshold. The spacing error was determined by comparing the buffered lead aircraft position with own aircraft position, referred as *constant time delay* algorithm.[1]

About 4 NM from the threshold the FDMS functionality is switched off, to enable deceleration to the aircrafts' own *Final Approach Speed* (FAS).

2.4 Improved planning of CDA initiation

Once started, the CDA profile should not be intervened by ATC unless in case of impending loss of separation. Therefore initiation and execution of a CDA in a TMA should be well planned to maintain traffic throughput without impairing safety. It is proposed to start arrival management well before top-of-descent (T/D). In this study the arrival management horizon was set to a distance of around 120NM from the airport. This requires executive control in an *extended* terminal airspace (ETMA).

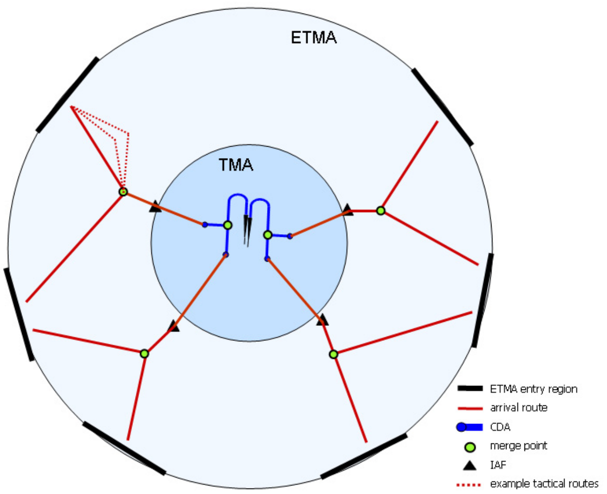

Figure 5: Improved inbound traffic flow control by use of RNAV STARs with doglegs

In Figure 5 a generic airspace design is presented. By usage of fixed RNAV STARs and a time constraint[2] at the *Initial Approach Fix* (IAF), the inbound traffic flow control can be improved, and CDA initiation better planned. Results of simulation studies [5] suggest a required TMA metering accuracy of within ±30 sec. Path stretching doglegs are instructed by ATC for proper sequencing, merging and spacing within the ETMA and compliance with the CTA at IAF. Additional fine-tuning in time is accomplished by on-board speed control, the RTA function.

Preferably, a path stretching dogleg should be issued during cruise flight to avoid major path and speed interruptions during the descent. The descent can then be initiated at a later stage to fly an optimal descent path (e.g. an approximate 3° idle descent). A route extension issued during descent will result in a less steep (sub-optimal) descent path.

2.5 Enabling technologies

To implement the discussed CDA procedure into an ATM system to achieve the desired throughput, enabling technologies may be needed:

- Ground systems to support the controller in handling high-density CDA traffic (i.e. enhanced arrival manager for accurate strategic planning of CDA approaches based upon RNAV routes, and advisory tools to assist executive controllers for their tactical sequencing and merging tasks).
- Air-to-ground data-link communication to take into account 4D trajectory onboard information
- Onboard systems and functions to accurately plan and fly the defined CDA.
- "ADS-B in" enabling air-to-air communication to support ASAS interval managed spacing.

Although in this paper we concentrate on the flight crew evaluation of the discussed CDA procedures, in the OPTIMAL project these enabling technologies have been taken into account in the overall validation activities [5]. For example, NLR has evaluated the usage of an advanced arrival manager AMAN and the Converging Runways and Approaches Display Aid CORADA for tactical sequencing and merging support.

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[1] Alternatively the actual lead aircraft position could be compared with predicted own aircraft position or, even better, using all available information (Kalman filtering).
[2] Alternatively ASAS merging & spacing or ground-based decision support tools could be applied

3 Cockpit operations and flight deck modifications

3.1 Time-based navigation

To support the flight crew in accurately flying the planned CDA, configuration cues were provided on the speed tape of the PFD. These cues advise the crew about the configuration change (including gear extension) speed and moment, with respect to the applicable constraints and to the goal of being fully stabilized at 1000 feet AFL.

At the vertical revision page on the FMS MCDU, the pilot can enter an RTA associated with the relevant waypoint, typically the IAF or runway threshold. The actual time error is presented on the left side of the ND (Figure 6).

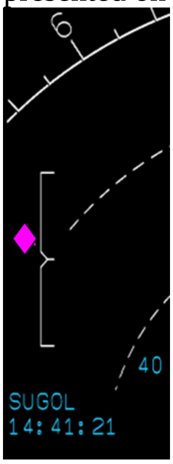

Figure 6: ND showing time error

Figure 7 gives an example of a configuration cue (F2) on the PFD speed tape, to advise the pilot about next configuration (CONF 2) change speed.

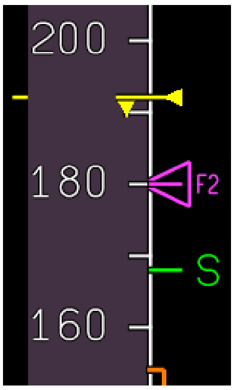

Figure 7: F2 configuration change cue on speed tape

At the moment the cue starts flashing, the crew is advised to set the next configuration. The reason of adding flashing to the cue symbol is twofold:

In case a scheduled configuration speed is close to a speed constraint, the optimal moment of changing configuration is difficult to determine, because the speed will often be stabilised for some amount of time around the speed constraint value, especially in the case of applying an *idle thrust* policy characterized by segments of constant speed (see also Figure 3). In most cases the configuration should be changed when the actual speed drops below the speed constraint; however pilots tend to act upon the cue the moment the actual speed equals the speed constraint.

Secondly, in case the actual speed profile deviates from the planned speed profile, the configuration cues may equal actual speed too early or too late. If, for example, the aircraft has more drag than expected, configuration speeds will be earlier reached than planned. The ETA at threshold will, in that situation, be too optimistic. Moreover, by changing configuration earlier than scheduled the situation will be worsened. To compensate (partly) the cue symbol will start to flash at the original scheduled point of the trajectory.

3.2 ASAS interval managed spacing

Entries related to ASAS merging and spacing operations are performed on the appropriate ASAS pages of the MCDU. On these pages the aircraft identifier of the traffic to follow, the instructed spacing (i.e. RTI) can be entered and the appropriate ASAS mode can be activated (Figure 8).

Figure 8: MCDU showing ASAS page

After activation the spacing error is show on the left side of the ND (Figure 9). In this example the RTI is 90 s, and the spacing error is about 6 s too far, or traffic to follow is 6 s too far ahead. The magenta symbol representing the spacing error is in the example positioned <u>above</u> the reference position (i.e. own aircraft representation being the middle of the tape) to indicate that speed and thrust has to be increased to correct the spacing error. That is airspeed and thrust has to 'move' in the same direction on their respective indicators, thus complying with the general *follow the needle* principle.

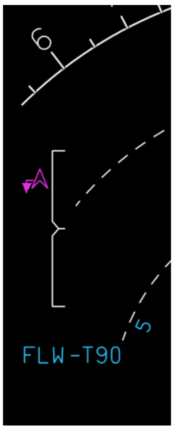

Figure 9: ASAS time spacing error indication

The top and bottom of the scale represent a spacing error of 10 s, and the magenta arrow pointing downwards indicates the trend of this error.

The calculated ASAS speed command could be fed into the flight guidance system and be flown by the autopilot/auto throttle system.

4 Flight crew evaluation

The ACDA procedures were evaluated by airline flight crews using a simulated Amsterdam Schiphol as destination airport. The following sections give a brief overview of the evaluation including results and recommendations.

4.1 Experiment setup

The experiment was conducted using NLR flight simulator GRACE. This simulator is capable of simulating various aircraft types with high fidelity. In this case, an A330-200 aircraft type was chosen, due to its known smooth aero-dynamical characteristics.

Figure 10: NLR flight simulator GRACE

Seven crews participated in the experiment. Flight deck modifications, discussed in the previous section, were used to support the crew in executing the procedures:

- Flap and gear deployment cues (PFD)
- FDMS functionality (MCDU, ND)
- RTA functionality (MCDU, ND)

Procedure, wind conditions, initial spacing and time of providing both path stretching dogleg and RTA at IAF by ATC were varied between scenarios. R/T was used for air-ground communication. Subjective data (i.e. questionnaires and observations) and objective performance data were collected.

4.2 Fixed RNAV route definition

All evaluated CDA procedures were approaches to runway 18R (see also Figure 11).

For best gradual transition from present day vectoring techniques in the TMA to fixed routing, daytime fixed RNAV transitions were derived from typical average vector tracks. Note that these routes are not necessarily optimized towards noise abatement.

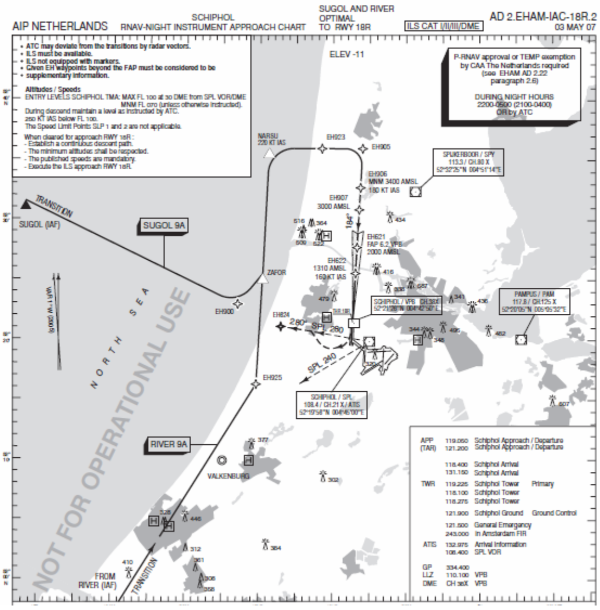

Figure 11: Concept CDA RNAV transitions to runway 18R at Schiphol airport

Three speed constraints at 20, 11, and 4 NM from runway threshold of respectively 220, 180 and 160 kts were included in this transition.

In Figure 12 the used RNAV STAR is shown containing three optional path stretching doglegs. Each dogleg extends the route by approximately 1 minute. Speed control was used for additional fine-tuning to achieve the desired time constraint (CTA/RTA) at SUGOL (IAF).

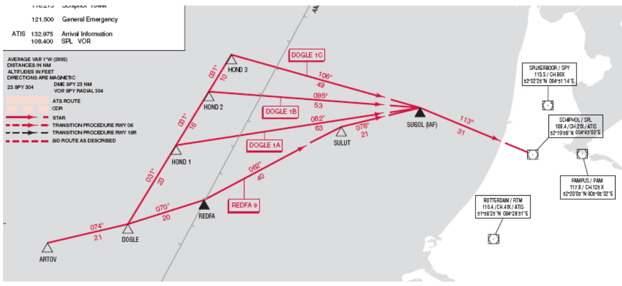

Figure 12: RNAV based path stretching legs

4.3 Results

Overall, the introduction of CDA approaches based upon fixed RNAV routes is well received by pilots. Main issues identified are:

- Predictability of speed changes/speed profile
- Predictability of configuration changes
- Effective monitoring of actual speed and timing versus planned profile

For all CDA procedures results show that the time constraint/interval at runway threshold can be met with sufficient accuracy under the simulated circumstances. Clearly, this is important to ensure required aircraft spacing during approach and landing in order to maintain throughput in high density traffic conditions. However, it should be noted that only a few up to ten seconds can be compensated within the TMA by the considered CDA procedures.

In the following subsections some specific results are described in more detail.

Idle thrust time-based navigation

Speed constraints combined with a fixed vertical path is a dominant factor regarding noise production and fuel consumption in time-based navigation procedures using an idle thrust policy. To illustrate this effect, in Figure 13 the engine fan speed (red) is drawn in relation to the flight trajectory (yellow).

Figure 13: Typical engine fan speed profile measured in idle thrust scenarios

Clearly after speed constraints the thrust settings are significantly increased to maintain speed, resulting in increased noise production and fuel consumption.

Furthermore, the speed target bug on the PFD was set to the upcoming speed constraint after entering the deceleration phase[3]. Consequently, the actual speed is for prolonged periods not equal to the target speed. 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.

Constant thrust time-based navigation

Looking at the typical commanded thrust profiles of ACDA operations based upon constant thrust time-based navigation shown in Figure 14, an unexpected negative effect on fuel consumption in some scenarios was revealed.

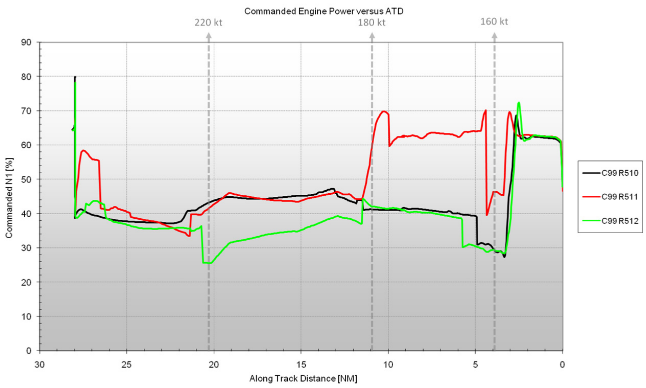

Figure 14: Typical commanded thrust profiles in constant thrust scenarios

Thrust settings were significantly increased in between the last two speed constraints of the approach. This effect can be explained by examining the flap configuration change moments with respect to along track distance in Figure 15.

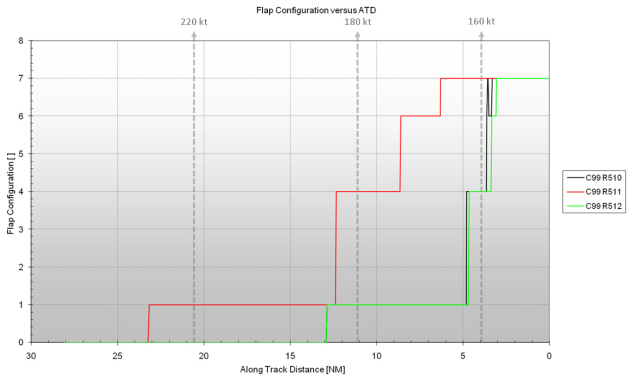

Figure 15: Typical flap configuration in constant thrust scenarios

The red line indicates a scenario in which the aircraft had to arrive earlier. Consequently, to gain time, configuration change speeds need to be chosen more in between the ATC speed constraints as illustrated in Figure 16. This implies a relative early configuration change scheme, creating more drag which needed to be compensated for by increased power settings to fly the planned speed profile.

The blue area indicates a region in which the average speed is higher than in case the configuration change speeds are chosen closer to the defined ATC speed constraints.

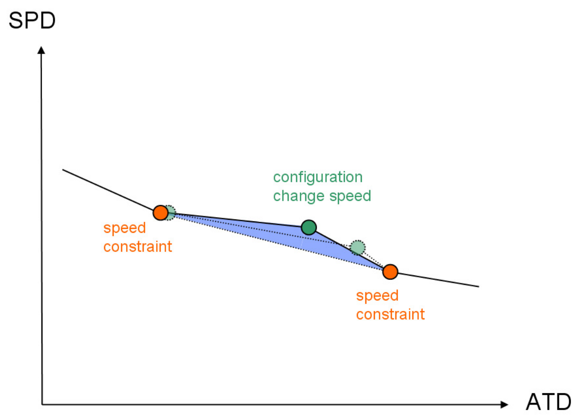

Figure 16: Control space for dynamic configuration change speeds

Apparently, position and value of ATC speed constraints, *nominal* configuration change speed scheme and time error are all interrelated, making the *adapted* configuration change speeds unpredictable. This is not acceptable for pilots.

[3] This is not fully compliant with Airbus HMI functionality, where the speed target is set to final approach speed.

Interval management
Deceleration segments due to speed constraints and the reduction to final approach speed are the cause of temporary spacing errors and subsequent speed corrections. This is inherent to the *constant time delay* algorithm. Each flight has its own deceleration characteristics on a given fixed vertical path, resulting in differences in the nominal speed profile. These differences introduce undesirable spacing errors. In particular the speed constraint at the 4 NM point was badly chosen, at that point also the FDMS function was switched off and the just created spacing error could not be corrected anymore.

Improved TMA entry planning
The introduction of RNAV based *doglegs* was preferred by pilots over the current practise of vectoring. The time constraint at IAF could be met with sufficient accuracy. This enables proper aircraft sequencing and spacing during initial descent. 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 spacing is desired.

Pilot-ATC interaction
The time constraints consisted of 6 digits. Receiving and reading back a 6-digit number was time-consuming and error prone for many pilots. Even if pilots read back the CTA correctly, errors were made in entering the RTA in the *Flight Management System* (FMS).

QNH setting
Switching from STD to QNH setting was done when cleared for the approach prior to the start of the CDA out of FL70, while the transition level is typically FL40. Compliance with FL70 altitude constraint is a concern.

Configuration cues presentation on PFD
A flashing cue to indicate the advised change moment to the next configuration, was not well received by pilots, because it forced the crew to monitor continuously the cue-symbol.

4.4 Recommendations

The following recommendations related to *conceptual* aspects are based upon discussions with pilots and performance assessment.

Reluctant use of speed constraints
Speed constraints and speed corrections, combined with a fixed vertical path are a dominant factor regarding noise and fuel consumption. Probably only a speed limit of about 180 kts at ILS interception is needed from a pilot point of view. Application of time based navigation or ASAS interval management will make additional speed constraints redundant or even disturbing.

Nominal configuration change speeds
A constant thrust policy with a monotone decreasing altitude and speed profile has the important potential advantage compared to the nominal idle thrust policy that thrust variations along the approach path are kept minimal. However, as explained in the previous section, the combination of dynamic configuration speeds with a time constraint *at runway threshold* may result in unacceptable early or late configuration changes and undesirable high thrust settings dependent on location and value of applied speed constraints. Therefore, it seems more appropriate in case of the constant thrust policy to move the time constraint towards *the start of* a time based navigation CDA procedure. Configuration change speeds may be kept nominal in this situation.

Flexible vertical descent profile
The capability of an aircraft to follow a ground-based fixed descent angle (i.e. 2° or 2½°) will vary greatly with wind. An aircraft at *Max Landing Weight* (MLW) with significant tail wind may not be able to follow the descent profile at the required speed without adding drag, which is very inefficient. In addition, adding drag may result in a higher than desired rate of deceleration or rate of descent[4]. If the

[4] In many aircraft, the selection of half speed-brakes is not recommended (Boeing), or possible (Fokker).

exact profile is to be flown, then additional thrust would be required. Adding drag and thrust is not desirable from a flight operational point of view. It is therefore recommended to permit a more flexible choice of (trajectory based) vertical descent profile dependent on aircraft performance in the design of the CDA procedure.

HMI modifications

The cockpit HMI should enable a crew to effectively monitor aircraft state against scheduled state and anticipate events related to aircraft state changes or system mode transitions ahead in time. Therefore, it is recommended to improve the HMI in the following areas:

Configuration cues should be predictable and unambiguous. It is suggested to provide these cues at the altitude tape on the PFD. The altitude tape allows, due to its larger scale, for presentation of multiple cues ahead of time without risking display clutter. Moreover, the aircraft altitude is continuously decreasing during a CDA which enables unambiguous indication of a (optimal) time instant without needing to flash symbology. It is anticipated that both speed tape and altitude tape are closely monitored during approach and landing.

In addition to the target speed, it is recommended to indicate the planned speed at the current position along the trajectory. This is especially helpful in case the actual speed is not equal to the target speed for prolonged periods during slowly decelerating descents.

Time error indication was presented on the ND. It is recommended to make the presentation intuitive with respect to sign. Furthermore, a trade-off was identified between speed profile update and allowable time error tolerance. This may impact algorithm[5] and HMI design. Presenting a small non-zero time error without a corrective action, although legitimate and operational acceptable, is human factors wise not desirable.

Flight mode annunciation should clearly indicate the special speed/thrust mode of the aircraft's autoflight system (i.e. "RTA SPD" and "FDMS SPD").

[5] Use i.e. in the algorithm a filtered time error (gain & notch filtering) as function of track miles to go [4].

5 Conclusion

Time-based navigation and ASAS interval managed CDA procedures at fixed RNAV routes with speed constraints have been evaluated from a pilot point of view. It can be concluded that under the tested conditions:

Time-based navigation using an *idle* thrust policy and ASAS interval managed CDA procedures are acceptable candidates to operate noise-friendly CDA procedures.

Time-based navigation using a *constant* thrust policy combined with *dynamic* configuration speeds showed negative effects on fuel efficiency and flight operation in case the time constraint is defined at the runway threshold.

Fixed RNAV STARs with path stretching doglegs combined with a time constraint at the TMA entry point is an acceptable candidate to improve adherence to the inbound planning during initial descent.

Finally, reluctant use of speed constraints in the approach, use of nominal configuration change speeds, a flexible vertical descent profile, and some HMI modifications are recommended.

References

[1] OPTIMAL project, www.optimal.isdefe.es

[2] Van Boven M. Development of noise abatement approach procedures. *10th AIAA/CEAS Aeroacoustics Conference*, Manchester, UK, AIAA-2004-2810.

[3] Den Boer R G, et al. *Sourdine II D9-1 Final Report*. Version 1.1, National Aerospace Laboratory NLR, 2006, www.sourdine.org

[4] Barmore B.E., et al. Simulation results for Airborne Precision Spacing along Continuous Descent Arrivals. *ICAS2008, 26th Congress of the Aeronautical Sciences*, Anchorage, USA

[5] Muynck R.J. de, et al. Enabling technology evaluation for efficient continuous descent approaches. *ICAS2008, 26th Congress of the Aeronautical Sciences*, Anchorage, USA.