Airborne Spacing: Flight Deck View of Compatibility with Continuous Descent Approach (CDA)

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This paper reports on an experiment conducted with airline pilots on a full flight simulator. The objective was a) to confirm the feasibility of airborne spacing with speed and lateral managed modes and b) to assess the compatibility of airborne spacing and continuous descent approach (CDA). The overall feedback was globally positive and consistent with previous experiments. All pilots found airborne spacing feasible from cruise until 2000ft, although more sensitive during the approach phase than in initial descent. The speed and lateral managed mode were well accepted. The pilots agreed that performing a CDA while maintaining spacing was feasible. The spacing was well maintained within the tolerance of 5s in initial descent (95% containment within ±2.1s). However, a cross-track error in approach led to larger deviation (95% containment within ±5s) and extreme values outside the tolerance. The cost induced was in the order of 115kt additional speed changes for the complete descent phase. In the terminal area, the route structure and altitudes were already optimised to allow a continuous descent from FL100.

Acronyms

AAL = Above Airport Level
ADS-B = Automatic Dependant Surveillance – Broadcast
ASAS = Airborne Separation Assistance System
ATC = Air Traffic Controller
ATIS = Automatic Terminal Information Service
CDA = Continuous Descent Approach
FAF = Final Approach Fix
FCU = Flight Control Unit
FMS = Flight Management System
FMA = Flight Mode Annunciator
IAF = Initial Approach Fix
ILS = Instrument Landing System
MCDU = Multi Purpose Control and Display Unit
ND = Navigation Display
PF = Pilot Flying
PFD = Primary Flight Display
PNF = Pilot Non Flying
RNAV = aRea NAVigation
TCAS = Traffic alert and Collision Avoidance System

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I. Introduction

AIRBORNE spacing involves a new task allocation between controller and flight crew envisaged as one possible option to enhance the management of arrival flows of aircraft. It relies on the ability of the controller to task the flight crew to maintain a given spacing with respect to the preceding aircraft. The motivation is neither to transfer problems nor to give more freedom to the flight crew, but to identify a more effective task distribution beneficial to both parties without modifying responsibility for separation provision[1]. Airborne spacing assumes air-to-air surveillance (ADS-B) along with cockpit automation (ASAS). No significant change on ground systems is initially required.

Airborne spacing for sequencing and merging arrival flows of aircraft is being studied, in particular at NASA, Mitre and EUROCONTROL. The air perspective was addressed through model-based and human-in-the-loop simulations[2,3,4,5] which showed the feasibility of the concept, mainly for in-trail situations. In addition, flight trials were conducted with experimental aircraft to confirm the results obtained[1,7,8]. In[1,7], trials were performed in the terminal areas, on in-trail situations with turns and wind effect, and using different speed control modes (from manual with the support of display cues to a fully automatic). The spacing task was performed successfully with a small deviation of inter aircraft spacing at runway threshold, and with a limited impact on workload although the perceived head-down time was higher. The ground perspective was also considered for enroute and terminal area through model-based and human-in-the-loop experiments[9,10,13,17]. More recently, flight trials and human-in-the-loop simulations[15,16] studied procedures and tools, based on trajectory oriented operations, integrating ability to perform continuous descent approach (CDA) while managing spacing. Theses studies showed that continuous descent can be efficiently conducted under moderate and high traffic load while accurately respecting a given spacing at a metering point.

The work performed at the EUROCONTROL Experimental Centre has allowed the development and refinement of a set of spacing instructions for sequencing and merging arrival flows of aircraft[11]. To gradually assess their operational feasibility, potential benefits and limits, two streams of air and ground experiments were conducted. The previous air experiments showed the feasibility of the spacing task from a flight crew perspective, initially with a simple assistance (graphical cues and speed selected mode). The air experiments conducted in 2004 and 2005 considered the complete descent phase with the preceding aircraft under airborne spacing and assessed the effect of different positions in the chain in simulating varied target speed profiles[12]. The subsequent air experiment conducted in 2005 in a fixed based cockpit simulator aimed at going a step further by assessing the use of a speed managed mode from cruise until automatic disengagement at 2000ft[14]. From all these experiments, pilots reported benefits in terms of situation awareness, accuracy of spacing, reduction of communications, but expressed concerns in terms of flight efficiency.

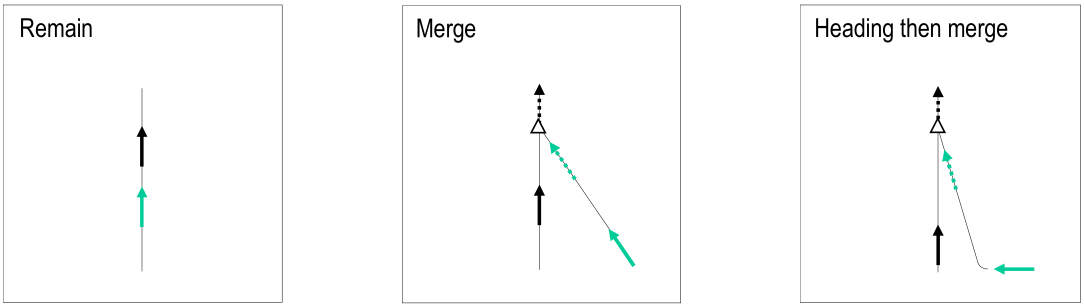
An experiment took place on a A330 full flight simulator at the Technical University of Berlin in February 2007. The objective was firstly to confirm the feasibility of airborne spacing with speed and lateral managed modes in a full flight simulator and, secondly, to assess the compatibility of airborne spacing and continuous descent approach (CDA). The paper presents the main findings from this experiment. It is organised as follows: the two next sections will present the spacing instructions and the cockpit interface. The two following sections will briefly describe the technical environment and the simulator characteristics. The next ones will present the experiment design and setup and the main findings.

II. Spacing Instructions

The controller tasks involve sequencing aircraft with the same strategies as today. When appropriate, he/she can task the flight crew to execute an instruction with respect to a designated aircraft (target). Three spacing instructions are proposed and can be applied throughout the arrival sectors, from top of descent down to final approach. These instructions require aircraft to achieve or maintain a particular spacing on common or converging trajectories (Figure 1). For example, with a “heading then merge”, the task of the flight crew is defined as follows: (1) in order to achieve the desired spacing, the flight crew flies an initial heading issued by the controller, and initiates the resume action when the desired spacing is achieved; (2) in order to maintain the desired spacing, the flight crew adjusts the aircraft speed. It should be noticed that the aircraft is not following the target – it is on his own navigation or on vector as instructed by the controller.

As for any standard instruction, the use of spacing instructions is at the controller’s discretion, and he/she can decide to end it at any time. The flight crew can only abort a spacing instruction in case of a problem onboard such as a technical failure. The controller should respect the same conditions as today for sequencing, e.g. compatible aircraft speeds. The use of spacing instructions is composed of three phases: (1) target identification, in which the controller designates the target aircraft to the flight crew, (2) issuing of the spacing instruction, and (3) termination of the spacing instruction. An example dialogue between controller and pilot is as follows:

1. Controller designates the target aircraft using e.g. transponder code ("XYZ, select target 4522")
2. Flight crew identifies target aircraft ("XYZ, target 4522 identified, 8 o'clock, 30 miles")
3. Controller confirms the identification ("XYZ, target 4522 correct")
4. Controller, when appropriate, issues the spacing instruction ("XYZ, continue present heading then merge WPT 90 seconds behind target")
5. Flight crew continues on heading, then initiates direct when spacing achieved ("XYZ, merging WPT"), then adjusts speed to maintain 90 seconds
6. Controller, when appropriate, cancels spacing ("XYZ, cancel spacing, speed 180 knots")



Remain

To maintain an along track spacing by speed adjustments

Both aircraft are on common trajectories

Merge

To maintain a predicted spacing at a waypoint by speed adjustments

Both aircraft are direct to waypoint

Heading then merge

To achieve then maintain a predicted spacing at a waypoint by a direct to the waypoint then by speed adjustments

Target is direct to waypoint

Figure 1. Spacing instructions.

III. Cockpit Interface

An initial design of the ASAS interface was proposed in 2000 and has been constantly improved following pilot suggestions and Airbus design principles. Initially, it was decided to solely rely on graphical cues to support airborne spacing, without any automatic mode (no coupling to the autopilot or to the Flight Management System). The motivation was twofold. Firstly to understand what flight crew could achieve in a manual speed ("selected") mode, and secondly to restrict the modifications required during initial phases of implementation. A managed speed mode was introduced in 2005. In the present experiment, the ASAS features consisted in: two speed modes, two lateral modes, a speed cue on the PFD, new graphical indications on the ND, and new MCDU pages for data input.

The two ASAS speed modes (selected and managed) were used for acquiring and maintaining the required spacing through speed adjustments. In the speed managed mode, the speed followed was computed by ASAS and displayed as a normal speed managed bug on the PFD (magenta triangle, Figure 2). In the speed selected mode, the speed followed was selected by the flight crew and displayed as a normal speed selected bug (cyan triangle, Figure 2). The suggested speed computed by ASAS was displayed on the PFD as a magenta dot (Figure 2). In speed selected mode, to avoid inducing too many speed changes, the suggested speed was rounded to multiple values of 5kt. As for a normal speed mode, when ASAS was engaged, the flight crew has the ability to switch from one to the other ASAS speed mode by pulling or pushing the speed knob on the FCU. No specific ASAS indication was provided on the FMA.

The two ASAS lateral modes (selected and managed) were used to perform the resume turn of a "heading then merge". In ASAS lateral managed mode, the NAV mode was armed on the FMA during the heading phase and the resume turn was automatically performed once required spacing was reached. In ASAS lateral selected mode, the aircraft remained on HDG mode and the resume turn was manually performed by the pilot as a normal direct-to. The flight crew had the ability to switch from one to the other ASAS lateral mode by pulling the FCU heading knob.

On the ND, the following indications were displayed (Figure 3): target aircraft information, spacing indications and, depending on situations, specific advisories (e.g. to perform the direct-to when in "heading then merge"), and caution or warning messages (e.g. when outside the tolerance margins).

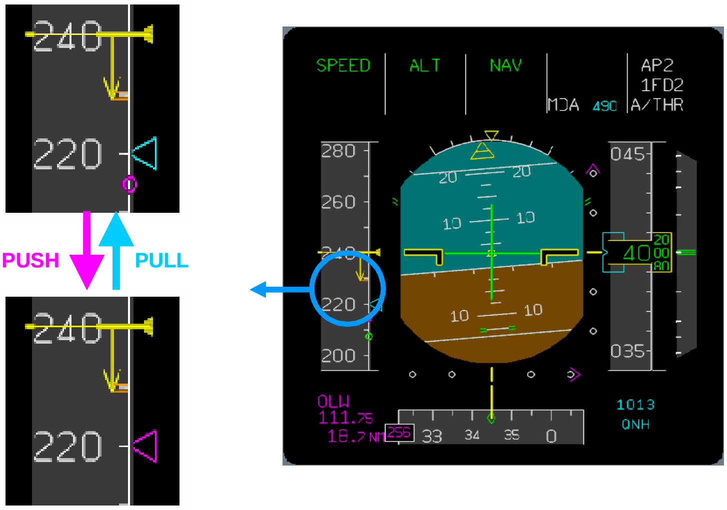


Figure 2. ASAS speed indication of the PFD in speed selected (top) and speed managed (bottom) modes.

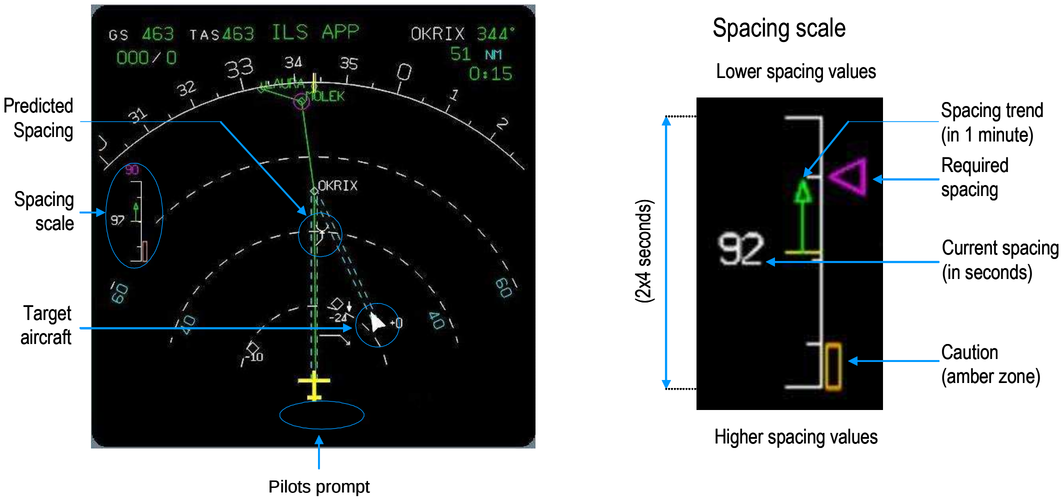


Figure 3. ASAS indications on ND (left) and detail of the spacing scale (right).

IV. Full Flight Simulator

The full flight simulator (Figure 4) is an Airbus A330 located at Technische Universität Berlin (TUB) and operated by ZFB (Zentrum für Flugsimulation Berlin). This simulator manufactured by CAE is certified JAR Level D for training and includes full motion (with six degrees of freedom) and a wide visual display (EP1000CT) for the external view. Besides its use for training, this simulator can also be linked to a Scientific Research Facility (SRF). In that case, the simulator uses a second host computer based on IBM RISC 6000 with an ATM network and different research capabilities. This simulator reproduces the complete flight controls, panels, displays and systems of a real aircraft, allowing pilots to perform all the usual flight tasks. An instructor panel placed in the back of the simulator gives control on external parameters such as the technical status of the aircraft, the atmospheric conditions (e.g. wind, visibility and wind-shear) and the ground infrastructure (e.g. glide slope inoperative).

The host computer of the SRF offers different programmers' interfaces in the domains display development, flight management and flight control and guidance. For this purpose the functionality of the original hardware is substituted by software modules which are extendable and modifiable. The following aircraft systems are completely available as software modules: Electronic Flight Instrument System and Display Management Computers (EFIS/ DMC), Flight Management System (FMS), Flight Guidance and Envelope System (FGES) including Autopilot and Autothrust.

Figure 4. A330 Full flight simulator.

A first version of the ASAS software was developed for the previous experiment in 2005. For the present experiment, new capabilities were added (speed and lateral managed modes, “heading then merge” function) along with improvements on the interface. In addition, to eliminate the risk of “over-runs” experienced in 2005 and caused by the limited processing power of the SRF host computer, it was decided to modify the system architecture to be able to run the complete ASAS software on another computer.

The new version of the software was working very satisfactorily according to the specifications. We had however to face one significant limitation with a downgraded guidance accuracy. This was caused by a problem of the lateral revision part in the software FMS. A quick fixing of the problem was not possible in due time, although it was demonstrated, that without calculated predictions (leaving out the gross weight during initialization), the guidance accuracy was within the limits and nearly equal to the real hardware. As a result, cross-track errors up to 1 NM between both trajectories occurred during turns and led to a large swing-over during interception of ILS (see example in Figure 5). These errors had an impact on the spacing and were disturbing for the pilots (although they were briefed).

Model-based simulations were performed to assess the effect of the cross-track error on the spacing during the final turn[18]. Using the data from the real time simulation, a similar scenario with a similar implementation of the speed guidance was performed with and without the cross-track error. The trajectory without cross-track error was obtained by projecting the target aircraft trajectory onto the instructed aircraft trajectory. The results show that the sole cross-track error induced a loss of spacing of about 3s (Figure 6). This is line with what was observed during test runs without gross weight that improved the lateral guidance accuracy and thus eliminated the cross track error.

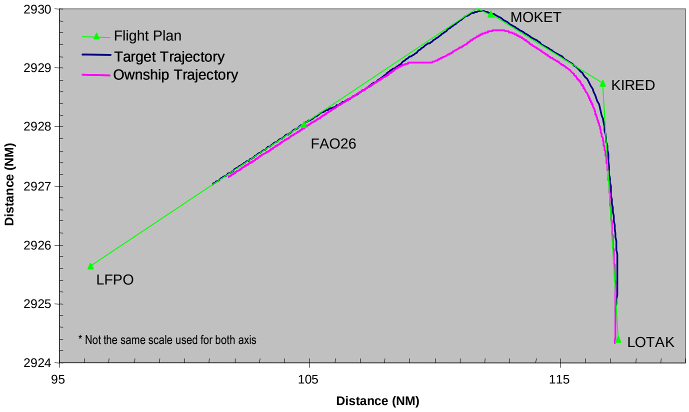


Figure 5. Cross-track error of 0.45NM between target and ownship aircraft trajectories during final turn to ILS (LOTAK-LFPO).

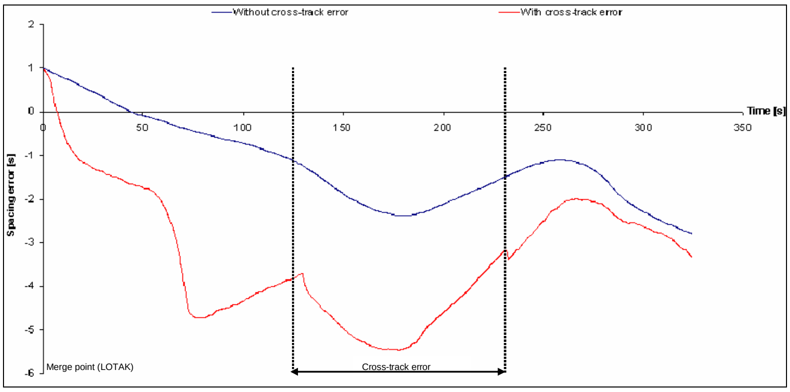


Figure 6. Impact of cross track error on spacing.

It should be mentioned that only one experimental display on each side was available to display the new ASAS symbols. We decided to use the experimental displays for ND as many new symbols had to be displayed, whereas an existing symbol on the PFD could be used to display the suggested speed. The suggested speed value was thus displayed in blue (rotation symbol) instead of magenta.

V. Experiment Design and Setup

A. Objective

The main objective of the experiment was to confirm the feasibility of airborne spacing with speed and lateral managed modes in a full flight simulator. A secondary objective was to assess the compatibility of airborne spacing and continuous descent approach (CDA).

B. Conditions

The two experimental conditions were:

- Non optimised descent: the flight crew was tasked (by priority order) to fly the aircraft and to maintain a given spacing.
- Optimised descent: the flight crew was tasked (by priority order) to fly the aircraft, to maintain a given spacing and to optimise their descent profile.

For each condition, it was recommended not to use the managed descent mode (DES[1]) as it does not give priority to the speed. In the non optimised descent condition, the open descent (OP DES[2]) mode was imposed to allow a comparison between both conditions. In the optimised descent condition, the flight crew could use also the vertical speed mode (V/S-FPA[3]) to adjust the rate of descent and thus avoid leveling-off.

Two runs, with two different scenarios, were performed in each condition to allow each participant to fly equally often as pilot flying (PF) and pilot non flying (PNF).

C. Participants and Schedule

The simulation was conducted over a period of two weeks from February 5th to 16th 2007. It involved five crews of two airline pilots mainly from Lufthansa and LTU which participated during two days (four hours on the simulator each day). Among the twelve participants[4], all Airbus rated, one was an experimental test pilot from

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[1] In managed descent mode, the flight path is maintained as defined by the FMGC (taking into account the flight plan constraints) and airspeed is controlled by the auto-throttle, while thrust is at idle. In case of saturation priority is given to altitude.

[2] In open descent mode, the autothrust controls the thrust and airspeed, and vertical rate is controlled by pitch. Lowering the nose is increasing airspeed and descent rate. Open descent mode has no specific vertical speed target and gives priority to airspeed in case of saturation.

[3] In vertical speed mode, the flight path is controlled by pitch and airspeed is controlled by the autothrust.

[4] Due to schedule problems, two pilots had to be substituted for training session. Therefore, twelve pilots participated to the simulation and for two crews, one of the pilots did not perform training runs. It was nevertheless decided to keep all the measured runs for data analysis as at least

Airbus, five were captains, two were senior first officers and four were first officers. The age ranges from 35 to 55 (mean 43), experience from 5,200 to 19,000 hours (mean 9,100), experience with Airbus from 2,000 to 9,000 hours (mean 5,400). Seven of the participants were newcomers not familiar with airborne spacing. The program covered a general briefing, four training runs on the simulator and four measured runs for each crew, enabling pilots to alternate functions (PF and PNF). Each run lasted about one hour. A general debriefing concluded each session.

D. Simulated Environment

The airspace was based on the one used in the 2004 ground experiment (derived from the Paris area) and consisted in enroute arrival sectors and a terminal area (Figure 7). To use airborne spacing in the terminal area, specific trajectories have been introduced, from the two initial approach fixes (IAFs) to the final approach fix (FAF) via a merge point. Following pilot comments made during previous experiments, the route structure in the terminal area was optimised and altitudes were raised (FL100 and FL120 after IAFs).

The measured flights lasted approximately 40 minutes and consisted in arrivals to an airport, with four flight phases: cruise, initial descent (from top of descent to IAF), initial approach (from IAF to FAF) and final approach (from FAF to full stop landing).

Recordings from the 2004 ground experiment were used to simulate the ATC environment. Each flight was immersed in a traffic recorded, thus providing realistic voice communications (and party-line), the display of TCAS traffic (when within range) and the visual display of the target aircraft. Although all ATC instructions were recorded, a pseudo-controller was present on the frequency to confirm the target positioning made by the crew, re-issue an instruction in case it was missed or misunderstood, and answer any request from the crew (e.g. descent).

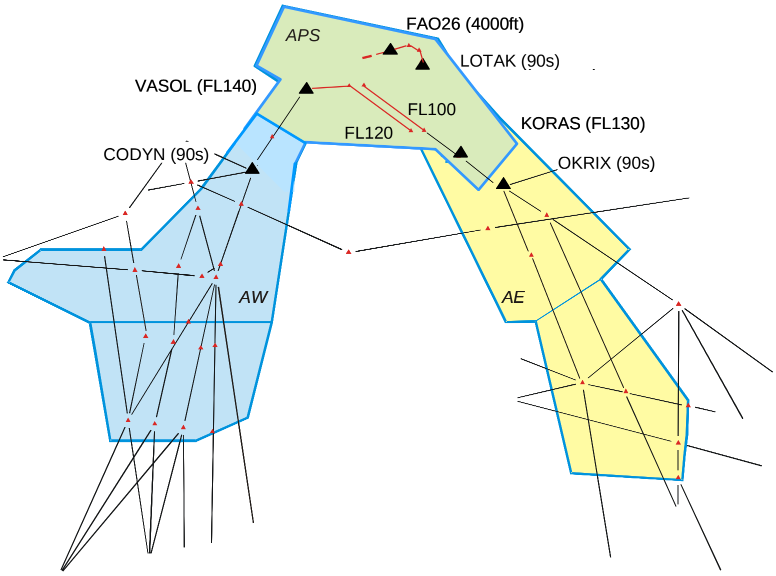

Figure 7. Airspace (simplified map) with enroute arrival sectors (AW and AE) and terminal area (APS). Initial approach fixes were VASOL and KORAS, and final approach fix was FAO26. Merge points were CODYN, OKRIX and LOTAK.

E. Flight Crew Tasks

Flight crews were tasked to fly the simulator as they would do in a regular flight, performing their usual tasks, including communications with ATC and checklists. Automatic Terminal Information Service (ATIS), navigation charts and checklists were provided. Given the phase of flight, flight crews were also tasked to take the latest ATIS and to perform their arrival preparation and briefing. It should be stressed that pilots were not authorized to modify route or change altitude, unless explicitly instructed by the controller.

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one of the pilots performed the training, and no significant impact on the results was observed (data analysis was made with and without those runs).

The flight crew had to perform successively, with a tolerance of ±5s, two spacing tasks:

- A "merge" at 90s to CODYN or OKRIX.
- A "continue heading then merge" at 90s to LOTAK, until the automatic ASAS disengagement at 2000ft AAL.

For both spacing tasks, the target was an Airbus A320 itself under spacing. For the "heading then merge", the target was either the same as for the "merge", or an aircraft coming from the other IAF. In addition, the flight crew was tasked to optimise the descent profile in optimised descent condition. Concerning the flight task distribution, following today's practices, it was suggested that the PF would control the flight parameters through the FCU and that the PNF would perform the data input in the MCDU. Both pilots would monitor the spacing.

VI. Main Findings

The main findings are presented in two parts: human factors, discussing the comments and workload assessment; effectiveness addressing achieved performance, cost induced and descent profiles[5].

A. Human Factors

The feedback was globally positive and consistent with previous experiments: all pilots found airborne spacing feasible and compatible with their usual flying task, from cruise until 2000ft. They reported many benefits: increased situation awareness (flying standard trajectories and knowledge of preceding aircraft), reduced workload for both controllers and pilots (reduction of communication), better organised flows of traffic and optimised route structure (trajectories and altitudes). Safety was perceived as slightly improved mainly due to a better situation awareness and a reduction of communications.

During initial descent, the spacing task was found efficient and accurate by all crews that performed it in speed managed mode. The ASAS lateral managed mode was also felt useful and used by all crews to perform the resume turn, thus avoiding time-critical manual 'direct-to'. However, the maintenance of spacing was felt more sensitive during approach phase. Some pilots were concerned by a possible conflict between the airborne spacing speed and the flaps scheduling (issue of compliance with Standard Operational Procedures). Thus, these pilots preferred switching to speed selected mode to retain control of the speed. This concern was reinforced by the different aircraft type (A320 for target and A330 for instructed aircraft) and the cross-track error that led to a drift of spacing during the final turn to the axis. Pilots perceived that the flight efficiency could be slightly degraded compared to today (fuel consumption, noise and passenger comfort). They were concerned by the handling of degraded situations (e.g. strong cross or tail wind) and stressed the need to develop robust recovery procedures (e.g. unplanned behaviour of target aircraft on final).

The pilots agreed that performing a CDA while maintaining spacing was feasible. They reported that an additional assistance would be needed to further optimise the descent under airborne spacing. Some pilots suggested that ASAS should include a specific managed descent mode to harmonize 3D profiles between all aircraft, others mentioned the need to have more anticipation for speed managed mode in order to achieve a smooth idle descent.

The assessment of pilots' workload obtained through NASA-TLX questionnaires shows that the spacing task generates a moderate level of workload without affecting the pilots perceived level of performance. It shows also no clear effect of the condition, suggesting that the optimisation of the decent profile generated no additional workload. However, some pilots were more comfortable with the open descent mode, especially during approach as this mode provides more availability than the vertical speed mode. In both conditions, the pilots reported an increased level of workload on final approach due to multiple tasks to perform (intercept of localizer, intercept of glide slope, speed reductions, flap setting, maintain of spacing).

The interface was found totally usable. ASAS displays on PFD, ND and MCDU were found intuitive and comprehensive, although some minor aspects should be improved (e.g. some cases of cluttering of the ND). The spacing scale associated to the trend arrow conveyed useful information to monitor the evolution of spacing.

B. Effectiveness

The effectiveness covers three aspects: performance, cost and descent profiles. The performance is measured by the achieved spacing (during the maintaining period, once it has been acquired). In line with pilots' feedback, it can be seen (Figure 8, left) that, during initial descent, the spacing was well maintained within the 5 seconds tolerance margins in both conditions, with an average error of –0.1s, about 1s standard deviation and a 95% containment of

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[5] It should be noticed that, due to technical problems, among the 20 measured runs, one run could not be considered, and for three others, the approach phase was not considered for the data analysis.

±2.1s. However, during approach phase, even though the average error remains small (–0.4s) with a 95% containment inside the tolerance margin (±5s), a larger dispersion of 2.4s and extreme values of 6.2s and –14.1s can be observed. This was caused by a cross-track error of 0.45NM that led to a sudden reduction of spacing, and worsened by two factors: a deceleration of the target occurring in this time frame, and lower deceleration capabilities of the instructed aircraft (A330) compared to the target (A320). The dispersion can be explained by varied pilots' strategies to cope with this situation.

Even if the guidance of a real aircraft would be more accurate, the problem experienced here raises the issue of discrepancies between flown trajectories. To eliminate or reduce this problem, navigation requirements may be imposed, typically in the form of Required Navigation Performance (RNP RNAV).

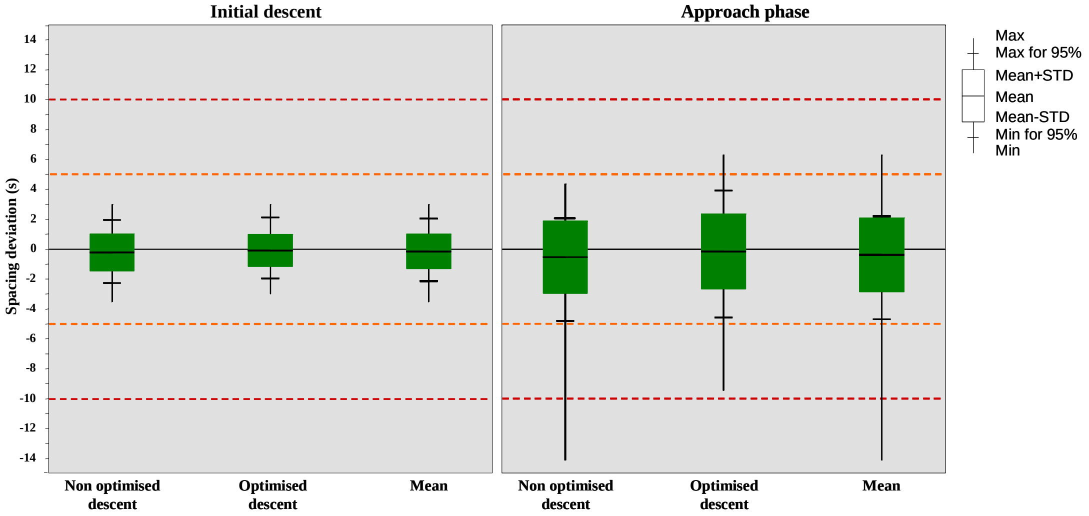

Figure 8. Spacing accuracy during initial descent (left) and approach phase (right).

The cost aims at capturing the effect of airborne spacing on the speed profile of the subject aircraft. It is represented by the amount of unnecessary speed changes compared to those of the target. It is obtained by subtracting the amount of target speed changes to the amount of subject aircraft speed changes. With ideal initial conditions (same speed and altitude, spacing equal to desired), a value of zero corresponds to a perfect replication of the target speed profile, a negative value to an improvement (i.e. smoothing of speed variations), and a positive value to a degradation (i.e. introduction of additional speed variations). If the speed profile is degraded, the spacing task may be more difficult to achieve for the following aircraft. Thus, when considering a chain of aircraft, the cost is not only an indication of flight efficiency but also as an indication of stability of the chain.

On average, about 115kt additional speed changes per flight was induced for the complete descent phase (55kt for initial descent and 60kt for approach phase, Figure 9). Whereas the condition had no major impact on the average values[6], the flight phase has a strong impact on the standard deviation and extreme values. In the approach phase, a large dispersion can be observed, caused by inter individual differences to handle the cross-track error (pilots' strategies and reaction times).

As defined, the cost integrates two main factors: the initial conditions (speed, altitude, spacing value) and the air system (flight crew, spacing guidance, aircraft). Typically, the cost can be impacted by a large initial spacing value that would automatically impose an acceleration. It can also be impacted by an inappropriate pilot reaction to a speed modification of the target (too late or early, too large or small speed adjustment) that could lead to an acceleration followed by a deceleration (or vice versa). A deeper analysis of the speed profiles flown allows an estimation of the different factors. It shows that during the initial descent, the initial conditions induced a cost of about 15kt and the air system induced about 40kt (acceleration and deceleration whereas the target speed was stable during this period). During the approach phase, an early triggering of the resume turn (for "heading then merge") induced a cost of 30kt and the cross-track error induced many small speed jumps that cost about 30kt in total.

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[6] The higher average value observed during approach phase in non optimised descent condition is due to the maximum value observed (110kts about the twice as much as average value). Statistical test made on data shows no impact of the condition.

Apart from the technical problems mentioned, these results suggest that improvements of the ASAS speed guidance are needed to reduce the cost. Two aspects should be considered: a further smoothing of the speed profile (with increased anticipation using target speed history) and a limitation of reacceleration, especially when close to final.

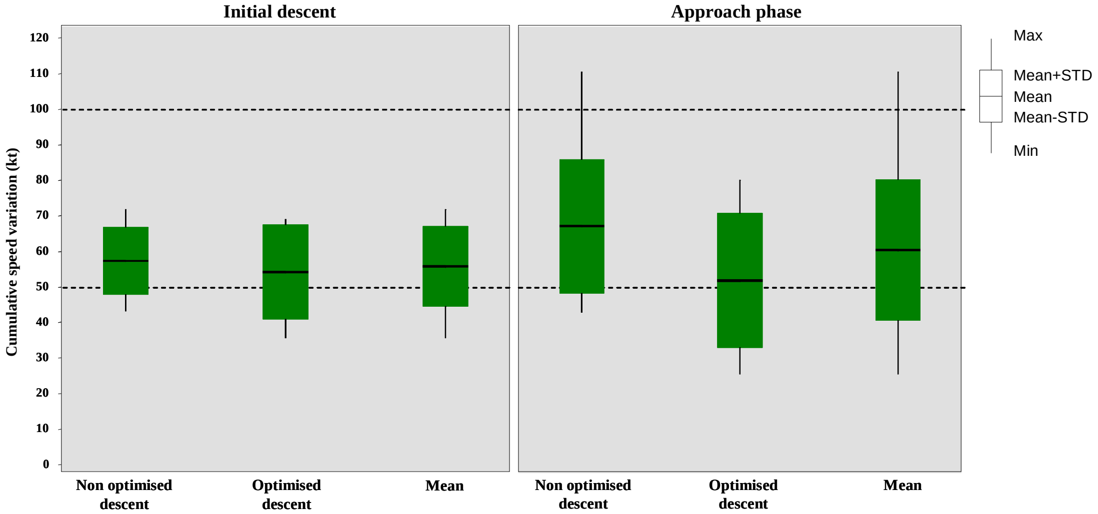

Figure 9. Cost induced during initial descent (left) and approach phase (right).

The descent efficiency is measured by the altitude difference between runs performed in optimised descent and in non optimised descent. In line with pilot feedback, descent profiles show that the CDA can be achieved while under airborne spacing, but in two steps (in initial descent and in approach phase) as the route structure required a level-off segment to provide separation, at FL120 and FL100 (Figure 11). In optimised descent condition, during initial descent, pilots could fly on average 800ft above the profile flown in open descent mode and with a maximum value of about 6000ft (Figure 11, left). However, no change is observed during approach phase (Figure 11, right) suggesting that, with this aircraft type (A330), the route structure and altitudes were already optimised to allow a continuous descent from FL120 or FL100 to the ILS interception (4000ft). According to aircraft type and descent capabilities, more adjustments may be required from the pilot to achieve a continuous descent.

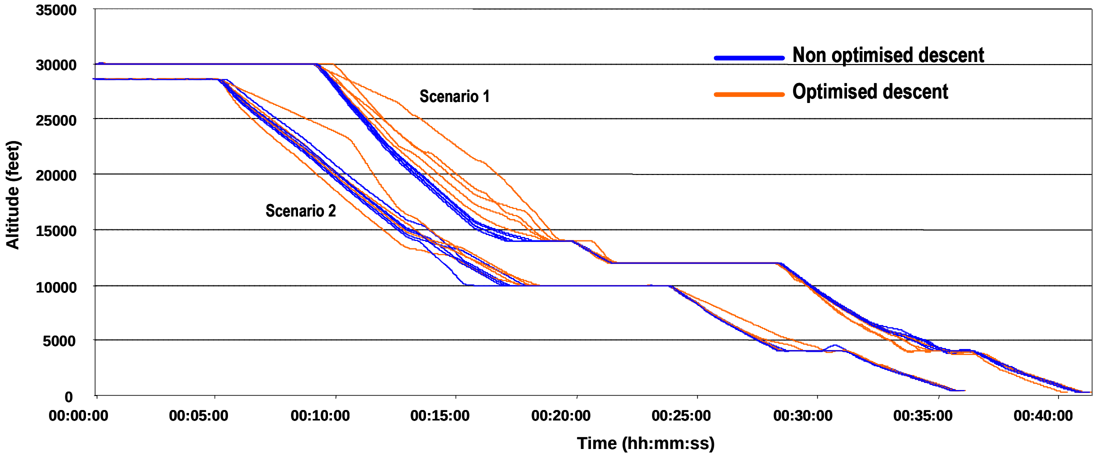

Figure 10. Altitude profiles.

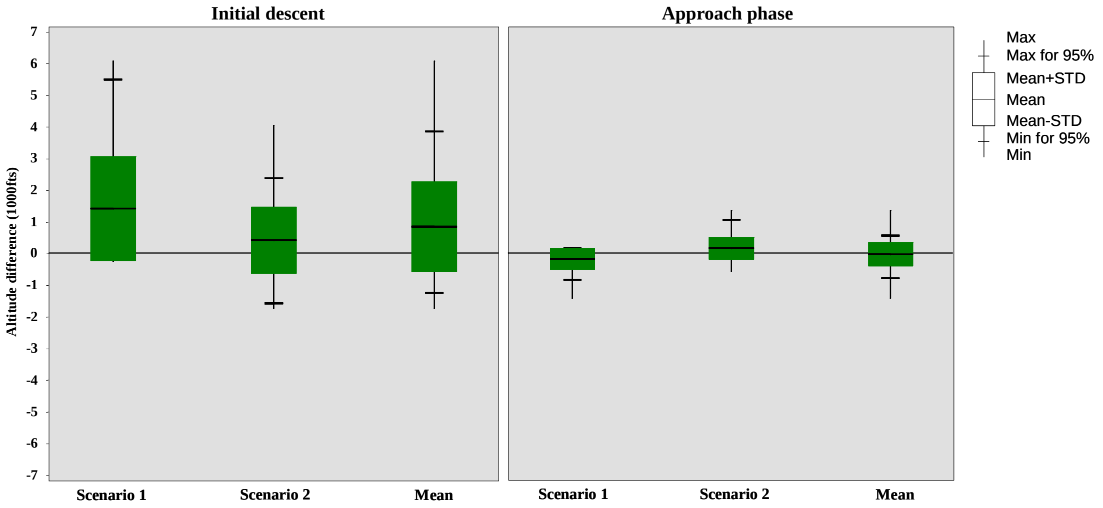

Figure 11. Altitude difference during initial descent (left) and approach phase (right).

VII. Conclusion

The objective of the experiment on the full flight simulator was to confirm the feasibility of airborne spacing with speed and lateral managed modes, and to assess the compatibility of airborne spacing and continuous descent approach (CDA). Five crews of two airline pilots participated during twice four hours on the simulator. The overall feedback was globally positive and consistent with previous experiments. All pilots found airborne spacing feasible from cruise until 2000ft, under nominal conditions. The maintenance of spacing was felt more sensitive during the approach phase than in initial descent, with a possible conflict between the airborne spacing speed and the flaps scheduling. Pilots reported many benefits: increased situation awareness, reduced workload, better organised flows of traffic, optimised route structure and slight increase of safety. They perceived however that the flight efficiency was slightly degraded and expressed some concerns about the handling of unexpected events on final. The speed and lateral managed mode were well accepted. The pilots agreed that performing a CDA while maintaining spacing was feasible. They reported that an additional assistance would be needed to further optimise the descent.

The spacing was well maintained within the tolerance of 5s in initial descent (95% containment within ±2.1s). However, a cross-track error in approach led to larger deviation (95% containment within ±5s) and extreme values outside the tolerance. Those large deviations were caused by a cross-track error occurring in a turn and worsened by a deceleration of the target. The cost induced was in the order of 115kt additional speed changes for the complete descent phase (55kt for initial descent and 60kt for approach phase). During the initial descent, the vertical profiles were improved in the ‘optimised descent’ condition compared to the ‘non optimised’. In the approach phase, no difference could be observed. In the terminal area, the route structure and altitudes were already optimised to allow a continuous descent from FL100.

It was shown that without cross-track error, the spacing drift would have been reduced. This raises the issue of identifying navigation requirements for airborne spacing. Improvements of the ASAS speed guidance are envisaged to allow reducing the cost: a further smoothing of the speed profile and a limitation of reacceleration, especially when close to final.

Acknowledgments

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