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COSPACE 2003 FLIGHT DECK EXPERIMENT
ASSESSING THE IMPACT OF SPACING INSTRUCTIONS FROM CRUISE TO FINAL APPROACH

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COSPACE 2003 FLIGHT DECK EXPERIMENT
ASSESSING THE IMPACT OF SPACING INSTRUCTIONS FROM CRUISE TO FINAL APPROACH
Volume I

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Abstract:
This report presents the results of the CoSpace flight deck experiment conducted in 2003. This experiment formed part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions for sequencing arrival flows. The previous flight deck experiments conducted in 2002 aimed at assessing the use of spacing in distance, from cruise to initial approach. The previous controller experiment conducted in 2002 introduced spacing in time and down to final approach. The present experiment is built upon these two previous experiments. Its objective was to assess, from a pilot perspective, the use of spacing in time and down to final approach. A recurrent secondary objective was to assess the evolutions of cockpit interface. Six crews of two airline pilots took part in the experiment on a part-task cockpit simulator. Flight crews were tasked to perform a spacing task in speed-select mode with the support of guidance cues, in addition to usual flight tasks.

The spacing task was considered as quite compatible with usual flying tasks despite an increase of mental effort which remained acceptable. Pilots noticed a slight focalisation on the spacing scale that might lead to reduce monitoring of flight parameters. Perceived benefits were: better understanding of the situation and anticipation, lower communication load due to less frequent exchanges with controllers. Time-based spacing was felt easier to handle. Some pilots asked for a managed spacing mode. The impact on flight crews' activity was assessed through the analysis of the speed actions. The average number of speed actions was less than 1 per minute and most were comprised between -15kt and +5kt. Every crew successfully achieved the spacing task: the deviation was maintained within the tolerance margins (5 seconds) with an average deviation of 1 second. Next steps will consist in assessing the effect of various reactions of preceding aircraft under airborne spacing. Experiments on a full-flight simulator are envisaged to assess feasibility in a more realistic environment.

SUMMARY

This report presents the results and findings of the CoSpace flight deck experiment conducted in June 2003. This experiment formed part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions for sequencing arrival flows. The previous flight deck experiments conducted in May and December 2002 aimed at assessing the use of spacing in distance, from cruise to initial approach. The previous controller experiment conducted in November 2002 introduced spacing in time and down to final approach. The present experiment was built upon these two previous experiments. Its objective was to assess, from a pilot perspective, the use of spacing in time and down to final approach. A recurrent secondary objective was to assess the evolutions of cockpit interface.

Six crews of two airline pilots took part in the experiment. Scenarios consisted of arrivals from cruise to final approach and lasted about 40 minutes. They were inserted in replays of controller exercises with ATC instructions and background traffic. Flight crews were tasked to perform a spacing task in speed-select mode with the support of guidance cues, in addition to usual flight tasks (communication with ATC, operational flight plan, arrival preparation and briefing). The experiment was carried out on a part-task cockpit simulator.

To analyse time-based spacing, four dimensions were considered: human shaping factors, flight crew activity, effectiveness and safety. To compare distance-based to time-based, the focus was put on human shaping factors. Compared to the 2002 experiment, although objectives were different, consistent feedback was received and similar trends were observed. Considering the 2003 objectives, the spacing task was feasible down to final approach, and time-based spacing was preferred to distance-based.

The overall feedback was positive. The spacing task was motivating and perceived as quite compatible with usual flying tasks despite an increase of mental effort which remained acceptable in the part-task simulation environment. Perceived benefits were: better understanding of the situation and anticipation, lower communication load due to less frequent exchanges with controllers. Time-based spacing was felt easier to handle. Even though information displays were appreciated, some pilots asked for a managed spacing mode.

The impact of time-based spacing on flight crews' activity was assessed through the analysis of the speed actions. Speed actions performed at the beginning aimed at acquiring the required spacing then speed actions were mostly triggered by changes in target state (descents and speed reductions). The average number of speed actions was less than 1 per minute, and most speed actions were adjustments comprised between -15kt and +5kt.

Every crew successfully achieved the spacing task: the spacing deviation was maintained within the tolerance margins (5 seconds). Most pilots looked for the exact required value (average spacing deviation of 1 second) even though it could lead to an increase in the number of speed actions. This was probably due to the "keep the bug aligned" culture. Largest spacing deviations were possibly due to the time needed to react to changes in target state. Effectiveness (fuel consumption, engine life, stability of chains of aircraft) could be impacted by some speed actions of large magnitude.

A possible gain in safety was mentioned, due to a better understanding of the context and a better involvement in the management of their situation with respect to the preceding aircraft. Pilots noticed a slight focalisation on the spacing scale that might lead to reduce monitoring of flight parameters. Moreover, they mentioned that every speed action was a potential source of error. In an operational context a managed spacing mode would be required.

Next steps will consist in assessing the effect of various reactions of preceding aircraft under airborne spacing. Improvements of the interface will be considered, mainly on the suggested airspeed. Experiments on a full-flight simulator are envisaged to assess feasibility in a more realistic environment and the impact on pilot monitoring.

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RESULTS ON EXPERIMENTS

PROJECT WEB SITE

www.eurocontrol.fr/projects/cospace/

ABBREVIATIONS AND ACRONYMS

Abbreviation	De-Code
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependant Surveillance – Broadcast
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATM	Air Traffic Management
CDTI	Cockpit Display of Traffic Information
DIR TO	Direct To
DIS	Distributed Interactive Simulation
EACAC	Evolutionary Air-ground Co-operative ATM Concept
EATM	European Air Traffic Management SBU
ECAM	Electronic Centralised Aircraft Monitor
EEC	EUROCONTROL Experimental Centre
EFIS CP	Electronic Flight Instrument System Control Panel
E-TMA	Extended Terminal Manoeuvring Area
EVP	EATM Validation Project
FAF	Final Approach Fix
FCU	Flight Control Unit
FMGS	Flight Management and Guidance System
ft	feet
FL	Flight Level
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
kt	knot
LFPG	Paris Charles-De-Gaulle Airport (ICAO code)
LFPO	Paris Orly Airport (ICAO code)
MASS	Multi Aircraft Simplified Simulator
MCDU	Multipurpose Control Display Unit
NASA-TLX	NASA Task Load Index
ND	Navigation Display
NM	Nautical Mile
PF	Pilot Flying
PFD	Primary Flight Display
PNF	Pilot Not Flying
R/T	Radio/Telecommunication
SBU	Service Business Unit

Abbreviation	De-Code
SSR code	**S**econdary **S**urveillance **R**adar **code**
TCAS	**T**raffic **C**ollision **A**lert **S**ystem
TIS-B	**T**raffic **I**nformation **S**ervice – **B**roadcast
TMA	**T**erminal **M**anoeuvring **A**rea
TOD	**T**op **Of** **D**escent
WPT	**W**ay**p**oin**t**

1. INTRODUCTION

The purpose of this document is to present the results and findings of the CoSpace flight deck experiment conducted in June 2003. This experiment forms part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions for sequencing arrival flows. The previous flight deck experiments conducted in May and December 2002 aimed at assessing the use of spacing in distance, from cruise to initial approach. The previous controller experiment conducted in November 2002 introduced spacing in time and down to final approach. The present experiment was built upon these two previous experiments. Its objective was to assess, from a pilot perspective, the use of spacing in time and down to final approach. A recurrent secondary objective was to assess the evolutions of cockpit interface.

The controller experiment conducted in 2003 is reported is a separate document (CoSpace 2004a).

The document is organised as follows:

- Section 2 introduces the principles of airborne spacing.
- Section 3 introduces the context and the objectives of the experiment.
- Section 4 describes the experimental design.
- Section 5 describes the data collection and analysis.
- Section 6 presents the results.
- Section 7 summarises the main findings.

2. PRINCIPLES

2.1. MOTIVATION

A new allocation of spacing tasks between controller and flight crew is envisaged as one possible option to improve air traffic management and in particular the sequencing of arrival flows. It relies on a set of new spacing instructions where the flight crew can be tasked by the controller to maintain a given spacing (in time or in distance) with respect to a designated aircraft. This task allocation, denoted airborne spacing, is expected to increase controller availability. This could lead to improve safety, which in turn could enable better quality of service and, depending on airspace constraints, more capacity. In addition, it is expected that flight crew would gain in awareness and anticipation by taking an active part in the management of their situation with respect to a designated aircraft. The motivation is neither to “transfer problems” nor to “give more freedom” to flight crew, but really to identify a more effective task distribution beneficial to all parties without modifying responsibility for separation provision. Airborne spacing assumes airborne surveillance (ADS-B) along with cockpit automation (Airborne Separation Assistance System, ASAS). No significant change on ground systems is initially required.

2.2. STATE OF THE ART

Pilot-in-the-loop simulations of in-trail following aircraft showed the feasibility of time-based spacing (Abbott, 2002, Agelii & Olausson, 2001). Based on a manual speed control mode, they did not reveal any expected oscillatory effects (Kelly & Abbott, 1984) but they highlighted an increase of pilot workload indicating the need for autopilot functions (Williams, 1983). A mathematical model (including pilots’ behaviour) of chain of aircraft under spacing in final approach could not show any unstable oscillations as well (Sorenssen & Goka, 1983). More recent pilot-in-the-loop simulations broadened their scope including aircraft on converging trajectories, with the objective of assessing the appropriate level of assistance onboard (Pritchett & Yankovsky, 1998; Pritchett & Yankovsky, 2000). The combination of descriptive information (display cues) and normative information (procedures) appeared to allow better anticipation and, hence, improve safety. Flight trials were conducted with different speed control modes for spacing (from manual to automatic) (Oseguera-Lohr et al., 2002). The spacing task was performed successfully with a limited impact on workload but a perceived head-down time higher.

2.3. PROCEDURES

The principles of airborne spacing considered here are to provide the controller with a set of new instructions for sequencing purposes. Airborne spacing is composed of three phases:

- Identification, in which the controller indicates the target aircraft to the flight crew.
- Spacing instruction, in which the controller specifies the task to be performed by the crew.
- End of airborne spacing, which marks the completion of the task.

From the flight crew perspective, the identification phase consists in selecting a preceding aircraft (the target). Then, through the new "spacing" instructions, pilots are tasked to acquire and maintain a given spacing with respect to the target until controllers cancel the spacing instruction. Finally, to end airborne spacing pilots deselect the target. As for any standard instruction, the use of spacing instructions is at the controller's initiative, who can decide to end its execution at any time. The flight crew however can only abort it in case of a problem onboard, such as a technical failure. In terms of responsibility, as opposed to visual separation, there is no transfer of separation responsibility.

Four spacing instructions for sequencing are proposed (Table 1).

Table 1: Sequencing applications.

Type of spacing	Same trajectory	Converging trajectory
Maintain spacing	*Remain behind*	*Merge behind*
Resume then maintain spacing	*Heading then remain behind*	*Heading then merge behind*

For illustration purposes, let us consider the situation of two arrival aircraft converging to a point, then following the same route to the airport. Today, the controller must ensure that the spacing is maintained, and therefore has to continuously monitor the situation and if necessary issue heading and/or speed instructions. With the spacing task, the maintaining of the spacing (in distance or in time) through speed adjustments is transferred to the flight deck (Table 2). Whereas the "land after" clearance can generally be given in final approach only (visual contact required), the spacing instruction can be issued earlier, typically before descent and regardless of visibility conditions, thanks to the display of the target aircraft onboard. However, applicability conditions shall be respected. In this example, prior to instructing, the controller must ensure that aircraft speeds are compatible, and the spacing at the converging point is not lower than the desired spacing. For more details about applicability conditions, see annex 1.

Table 2: A typical exchange between controller (left) and pilot (right).

Sequencing of converging aircraft:	
XYZ, select target 1234.	
	Selecting target 1234, XYZ.
The designation of the target aircraft is done through a unique identifier (here the SSR code). After selection and identification on the screen, the pilot replies:	
	XYZ, target 1234 identified, 2 o'clock, 30NM, 1000ft below.
The controller can then issue the spacing instruction:	
XYZ, behind target, merge WPT 90 seconds (8 miles) behind.	
	Merging WPT 90 seconds (8 miles) behind target, XYZ.
The pilot has to adjust his/her speed to maintain the spacing at the converging point and after the point. The spacing instruction will be ended by the controller when appropriate:	
XYZ, cancel spacing, reduce speed 220 knots.	
	Cancelling spacing, reducing speed 220 knots, XYZ.

2.4. TECHNICAL MEANS

On the controller side, the only required modification to the current working environment is the knowledge of aircraft ASAS equipage, for example through a field of the flight plan. In addition, graphical marking capabilities on the controller screen would be useful as a reminder of on-going spacing instructions as well as a support for co-ordination when transferring spacing instructed aircraft to next sector (Figure 1).

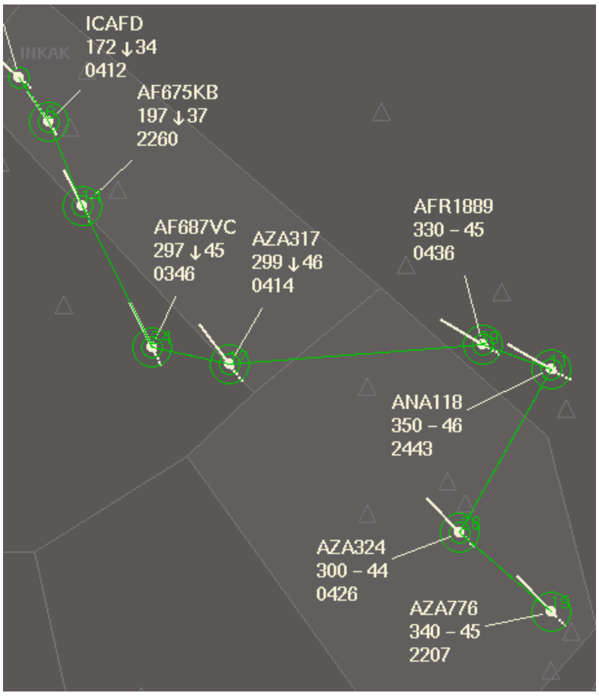

Figure 1: Controller interface with indications of aircraft under spacing instruction (green links between target and instructed aircraft).

On the cockpit side the spacing task requires the display of the target aircraft onboard the instructed aircraft. The Automatic Dependant Surveillance – Broadcast (ADS-B) is a surveillance means in a pre-operational state in which equipped aircraft transmit spontaneously their position and velocity (and eventually their trajectory). The Traffic Information Service - Broadcast (TIS-B) is an additional means to be used when some aircraft are not ADS-B equipped; position and velocity are transmitted via a ground station to equipped aircraft. The traffic data received through ADS-B or TIS-B is displayed on a screen in the cockpit. This capability is denoted Cockpit Display of Traffic Information (CDTI). In addition to the display of the target aircraft, assistance to maintain spacing is required, typically through graphical cues (cf. 4.7). This capability is usually denoted Airborne Separation Assistance System[1] (ASAS). Despite the similarity between terms, it should be noted that ASAS is completely distinct from the collision avoidance system ACAS/TCAS, which is a last resort system.

1 This term was introduced in 1995 at a time where the distinction between separation and spacing was not clearly identified by the ASAS community.

3. CONTEXT AND OBJECTIVES OF THE EXPERIMENT

3.1. STRATEGY AND APPROACH

One of the key aims of the project is to build an understanding of the potential impact of spacing instructions and of the evolutions induced or required with respect to today's ATC. Therefore, since its inception, the study follows an iterative process, in which every step (essentially real-time experiment) helps defining the next one. The stepwise strategy followed can be described along three dimensions:

- Operational: "start in cruise (in extended terminal manoeuvring area, E-TMA) and progressively get closer to the runway (in terminal manoeuvring area, TMA)".

- Validation: "start assessing usability (e.g. concept, procedures, interface) and progressively address impact on user activity (controller, pilot) and eventually on the ATC system (e.g. quality of control/flying, safety, efficiency)".

- Technology: "start with a basic working environment (e.g. paper strips, voice communications, no advanced tools, selected mode in the cockpit) and progressively introduce assistance and technology when need clearly identified (e.g. uplink of target selection, downlink of spacing parameters, controller spacing monitoring aids, managed spacing mode in the cockpit)".

Because of the inherent air-ground nature of the concept, both controller and pilot persopectives have to be considered. To limit risk in terms of development and execution, but mainly to be able to properly control experimental parameters, it was decided to conduct two separate streams of experiments (air and ground). Nevertheless, the consistency between the two streams is ensured essentially by relying on the same concept (applications, procedures, phraseology), the same operational environment (type of airspace, scenarios) and a unified validation framework (experimental plan, metrics).

3.2. PAST EXPERIMENTS

In order to get feedback on the concept, an initial air-ground experiment was carried out in 1999. Then, to assess the benefits and limits, two streams of air and ground experiments were conducted: 5 ground experiments since 2000 with in total 28 controllers from different European countries over 10 weeks; three air experiments since 2000 with in total 25 Airline pilots and 4 test pilots over 15 days.

Similarly to the ground side, air side investigations focused on upper airspace (E-TMA) with aircraft initially in cruise and starting their initial descent down to the initial approach fix (IAF). The first two experiments essentially provided usability assessment. The flight crews overall feeling was positive and new requirements for spacing-related information display were identified (EACAC 2001a, 2001b).

To get initial insight on flight crew activity, an experiment was conducted in May 2002 (CoSpace 2004b). Pilots stressed benefits, mainly understanding their situation with respect to the preceding aircraft, but also a risk of workload increase. Results showed that spacing could be maintained within tolerance margins. No correlation was found between number of speed actions and spacing accuracy. In terms of support, the usability of the existing interface was acknowledged, but additional guidance cues such as spacing trend and suggested speed, and eventually managed spacing mode were requested.

In terms of simulation realism, the lack of TCAS traffic display and party line was felt as a limitation. An experiment was conducted in December 2002 (CoSpace 2004b). The objective was to assess the impact of 3 tolerance margins (±0.25NM, ±0.5NM and ±1NM) on flight crew activity and effectiveness with additional guidance cues. The experimental design took advantage of previous controller-in-the-loop experiments and in particular its operational context and validation framework. The results showed that even though small tolerance margins required more effort and attention, the spacing task was performed successfully and fitted into the simulated flying activity. Moreover, evolution of guidance cues improved usability and improved simulation realism was appreciated. Pilots mentioned the same benefit and risk as in the May 2002 experiment.

3.3. VALIDATION MODEL

To ensure a coherent view between air and ground experiments, the air experiment validation model followed evolutions of the ground experiment validation model (CoSpace 2003a). In the context of the previous ground experiment, it was pointed out that the model (Figure 2 left) had limitations even though it provided a useful framework to support the analysis and put results in perspective. The main one was its inability to easily encompass human factors such as motivation, confidence or skills. The model was refined (Figure 2 right). The first level (acceptability) was re-scoped in terms of **human shaping factors** and includes human factors and usability issues. It provides feedback on the impact of the concept on human factors such as workload, confidence and teamwork. It also includes feedback on the concept usability. The **activity** level remained unchanged. It investigates the integration of the spacing task within the overall flight activity. It assesses the compatibility with existing tasks, procedures and strategies. The second modification concerns the outer levels. To highlight the necessary trade-off between **effectiveness** and **safety**, the two dimensions are now considered at the same level. The flight effectiveness level addresses the consequences of the spacing task on the quality of flying. In other words, it assesses the impact on the results of the flight deck activity at a more systemic level (spacing quality, fuel consumption, respect of scheduled time…). The flight safety level aims at analyzing if induced changes are acceptable in terms of safety and assessing the associated risks and the required mitigation means.

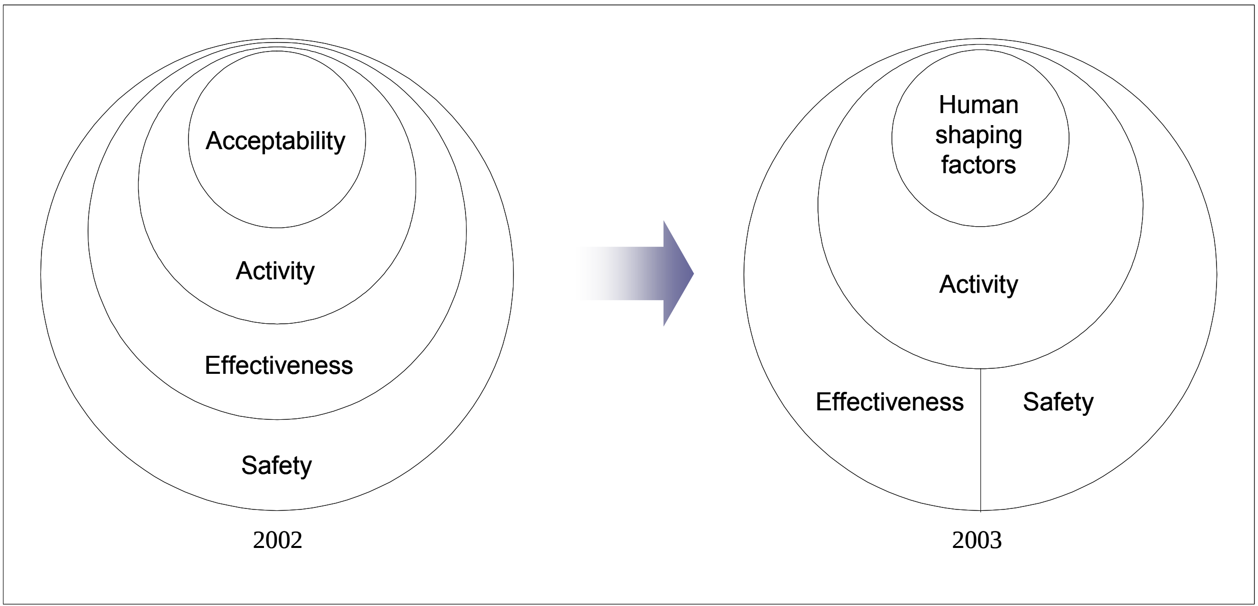

Figure 2: From 2002 to 2003 validation model.

3.4. OBJECTIVES

The objectives of the experiment were to assess:

- The feasibility of the spacing task in the **approach** phase from when flight crew workload increases due to landing preparation.
- The impact of using **time-based** spacing on flight crew activity and effectiveness in the descent and the approach phases by varying the initial spacing.
- The evolution of **cockpit interface**.

3.5. HYPOTHESES

Three sets of hypotheses were defined according to the experiment objectives, the principles of airborne spacing and flight crew activity.

The first hypothesis deals with the type of spacing. Time-based spacing is expected to be more accepted than distance-based spacing because:

- In distance-based spacing, the instructed aircraft needs to adjust immediately its speed on the target ground speed. Therefore, in approach, the instructed aircraft reduces speed further away from runway and at higher altitudes. In time-based spacing, the instructed aircraft attempts to fly the speed profile of the target aircraft (speed reduction at the same geographical point) (Abbott 2002).

- The same required spacing value could be used in cruise and in approach unless spacing shall be increased due to wake turbulence or to the integration of another aircraft.

- The time delay helps the pilot to anticipate his actions according to target's previous state[2].

The second hypothesis deals with the initial spacing deviation between the spacing instructed aircraft and the target aircraft. It is expected that a smaller initial spacing deviation induces a shorter "acquisition" phase and therefore more time spent maintaining the spacing during the "merge" phase. As it is thought to be more demanding to maintain rather than to acquire the spacing, it is expected that a smaller initial spacing deviation are more costly in terms of number of speed actions.

As for May'02 and December'02, the third set of hypotheses deals with the impact of the spacing task on pilot roles, PF (Pilot Flying) and PNF (Pilot Not Flying):

- The spacing instruction is expected to increase both pilots monitoring load, but put a higher demand on the PF, who is directly involved in maintaining the situation.

- The spacing task should also enable a reduction of the PNF's perceived communication load in reducing the number of Radio/Telecommunication (R/T) messages.

[2] The use of the time history to provide some form of anticipation is not fully investigated yet in the study.

4. EXPERIMENTAL DESIGN

4.1. EXPERIMENTAL PLAN

4.1.1. Independent variables

Given the experiment objectives, two main independent variables were defined: the type of spacing (distance-based versus time-based) and the initial spacing deviation (small versus large). The pilot function (PF and PNF) was considered as a secondary independent variable.

As for December'02 (CoSpace 2004b), it was decided to assess one spacing instruction to limit the number of independent variables. The "merge" instruction was selected because 97% of the instructions issued during the CoSpace November'02 ground experiment were "merge".

Both pilots flew a conventional flight for baseline purposes. This flight allowed pilots to compare conditions with and without spacing task.

4.1.2. Dependent variables

Following the previously described validation framework, we looked more specifically at the following dependent variables (items in bold are investigated in the present experiment (See Table 3 for the complete list of metrics and measures related to flight deck analysis).

- Human shaping factors: subjective feedback on motivation and perceived usefulness, workload and usability;
- Activity: number and magnitude of speed actions, interval between speed actions;
- Effectiveness: spacing accuracy;
- Safety: subjective feedback, losses of spacing, large speed magnitude.

Table 3: Dimensions, metrics and measures related to flight deck analysis (items in blue and bold are investigated in the present experiment).

High level objectives	Metrics	Measures
Human shaping factors	**Motivation and perceived usefulness**	**Subjective feedback**
	Workload	**Subjective feedback**
	Teamwork	Task distribution PF/PNF
	Usability (concept and tools)	**Subjective feedback,** number of errors, relative usage of displays
	Skill and training needs	Subjective feedback
Flight crew activity	Communicate with ATC	Number and duration of messages
	Fly the aircraft (pilot and navigate)	Flying tasks (actions on flight parameters)
	Acquire/Maintain spacing	**Number and magnitude of speed actions, interval between speed actions**
	Maintain situation awareness (collect and interpret information)	Subjective feedback, fixations, scanning patterns, delay before reaction to target events
	Perform briefing, check lists and cross check	Observations
Effectiveness	**Quality of flying**	Flight efficiency (fuel, speed profile,…)
		Respect of scheduled time of arrival
		Spacing accuracy
	Pseudo controller perspective	Respect of instruction (reaction time, …)
Safety	Error management	Predictive error model
	Flight errors	Alarms, actions omissions
	Spacing task-related errors	**Loss of spacing, large speed magnitude,** execution errors **Subjective feedback**

4.1.3. Experiment Run Plan

The experiment objectives led to a 2×2 design: type of spacing task (time-based, distance-based) × function (PF, PNF). In addition, the time-based spacing condition is split into in “small initial spacing deviation” (required spacing -10%) and “large initial spacing deviation” (required spacing +30%).

Each pilot flew the baseline run (without spacing task) once as PF. The resulting experimental plan is presented below (Table 4).

Table 4: Run plan.

Runs	Type of Spacing	Initial spacing deviation	Scenario	Pilot 1	Pilot 2
Run1	Without	N/A	LFPO	PF	PNF
Run2	Time	Large (90s + 30 %)	LFPG	PNF	PF
Run3	Time	Small (90s – 10%)	LFPO	PNF	PF
Run4	Time	Large (90s + 30%)	LFPO	PF	PNF
Run5	Time	Small (90s – 10%)	LFPG	PF	PNF
Run6	Without	N/A	LFPG	PNF	PF
Run7	Distance	8NM + 30%	LFPO	PNF	PF
Run8	Distance	8NM + 30%	LFPG	PF	PNF

4.2. SIMULATION PROGRAMME

The simulation took place between June 4th and 18th 2003. The programme covered a general briefing, initial training and 8 measured runs for each crew, enabling pilots to alternate functions (PF and PNF). A general debriefing concluded each session. Each session was planned to last 1.5 days. Crews who had not participated in December'02 experiment had a longer training period.

4.3. PARTICIPANTS

Six crews (2 European airline pilots each) took part in the experiment. Among the 12 participants, 4 were captains and 8 first officers. Five pilots had participated in December'02 experiment.

The age distribution is as follows:

Table 5. Participants age distribution.

Age	<30 years	[30-35]	>35 years
Number of pilots	1	6	5

A distinction is made between experience in flying Airbus aircraft and experience as a pilot.

Table 6. Participants experience in flying Airbus aircraft and in flying in general.

Experience	<3 years	[3-5]	>5 years
Flying Airbus aircraft	5	4	3
Flying in general	1	2	9

All pilots expressed a high level of motivation to participate in this study: a third chose 3 and two thirds chose 4 on a 4-point scale (see annex 3.1 and 3.2 for details).

4.4. SIMULATED ENVIRONMENT

The simulated airspace (derived from Paris area) and traffic were similar to the ones used for the CoSpace November 2002 ground experiment.

Flights consisted of arrivals to Paris Orly (LFPO) and Charles De Gaulle (LFPG) from cruise to the final approach fix. The airspace was adapted to airborne spacing by adding standard trajectories from the initial approach fix to the final approach fix. The main purpose of having a scenario on 2 different arrivals was to introduce variety in the exercises and consequently avoid repetitive approach briefings. The scenarios were nevertheless comparable and both lasted about 35 minutes of flight time. The runs were scripted accordingly to the use of the “merge” instruction made by controllers.

All runs consisted in three flight phases: cruise, initial descent (from top of descent, TOD, to IAF) and initial approach (from IAF to FAF). Events marking these phases were level instructions (“descend flight level 100” and “descend 3000 feet, QNH 1013” on LFPG and (“descend flight level 90” and “descend 3000 feet, QNH 1013” on LFPO) and target speed reductions to 250kt and 220kt.

Differences existed between the scenarios such as the initial descent altitude (FL090 for LFPO and FL100 for LFPG) and the localizer intercept distance (6.5 NM from the glide for LFPO and 2 NM from the glide for LFPG). Moreover, distance from IAF at the beginning of the runs and at the issue of the spacing instruction varied across flights:

- Start 125NM from IAF with a spacing instruction given 87NM from IAF (time-based on LFPG arrival).
- Start 156NM from IAF with a spacing instruction given 121NM from IAF (time-based on LFPG arrival).
- Start 125NM from IAF with a spacing instruction given 99NM from IAF (time-based on LFPO arrival).
- Start 110NM from IAF with a spacing instruction given 77NM from IAF (time-based on LFPO arrival).
- Start 125NM from IAF with a spacing instruction given 89NM from IAF (distance-based on LFPG arrival).
- Start 124NM from IAF with a spacing instruction given 99NM from IAF (distance-based on LFPO arrival).

The following figure (Figure 3) describes the simulated airspace and the trajectories of both the instructed and target aircraft.

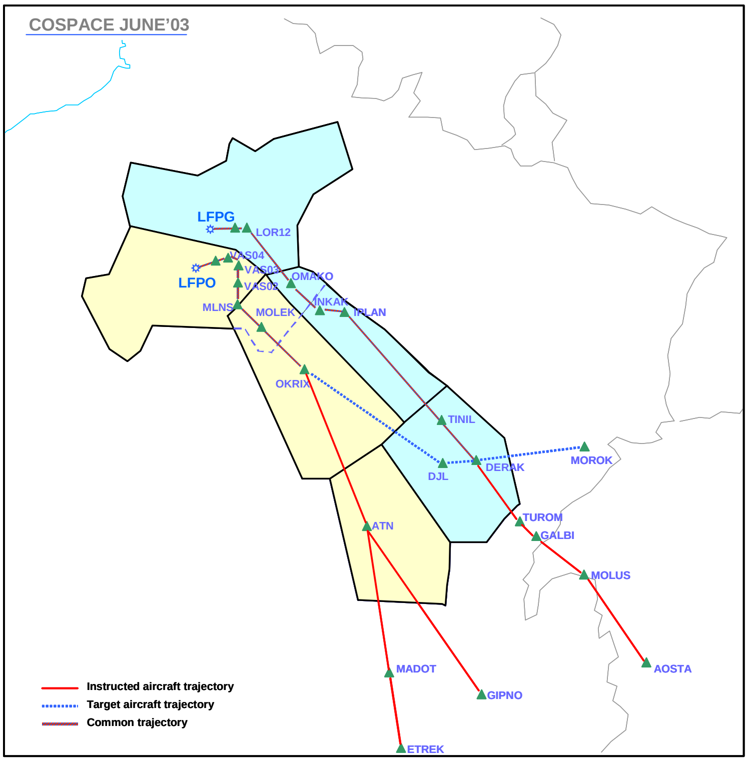

Figure 3: Simulated airspace and trajectories.

Each flight was "inserted" in an air traffic previously recorded with a controller, thus providing realistic voice communications (and party-line) along with a display of TCAS traffic when within range. In other words, an operational controller was controlling a realistic situation by giving instructions to pseudo pilots handling all the aircraft (planned cockpit simulator and background traffic). Regarding the aircraft corresponding to the cockpit simulator, pilot communications were omitted and plots removed from the recording. Consequently, the radio party-line included all the voice communications and in particular instructions for the cockpit simulator (except of course communications from cockpit simulator). The other traffic was generated by the Multi Aircraft Simplified Simulator (MASS) on the ESCAPE platform and recorded on a Distributed Interactive Simulation (DIS) manager. A “pseudo-controller” was present on the frequency in order to:

- confirm the target positioning made by the crew,
- reissue the proper ATC instructions in case an instruction was missed or misunderstood (wrong readback),
- answer any possible ATC request from the crew (e.g. “requesting descent”).

In addition to the flight plans used, controller’s instructions for the scenarios were scripted (content and time of occurrence) so that the observers and the “pseudo-controller” could follow the progress of the runs. Detailed scripts are presented in annex 2.

4.5. SPACING PROCEDURES

The spacing task is divided into three distinct phases:

- Target identification,
- Instruction of spacing,
- End of spacing.

The crew was tasked to adjust speed to acquire and maintain the spacing, following the suggested airspeed in the cockpit. For the "merge" instruction, two phases are identified (Figure 4):

- In the "merge" phase, target and instructed aircraft are direct to the merging point. The pilot is tasked to adjust speed to obtain the spacing when the target is over the merging point. After the target passed the merging point, the "merge" becomes a "remain".

- In the "remain" phase, target and instructed aircraft are following the same trajectory. The pilot is tasked to adjust speed to maintain the current spacing.

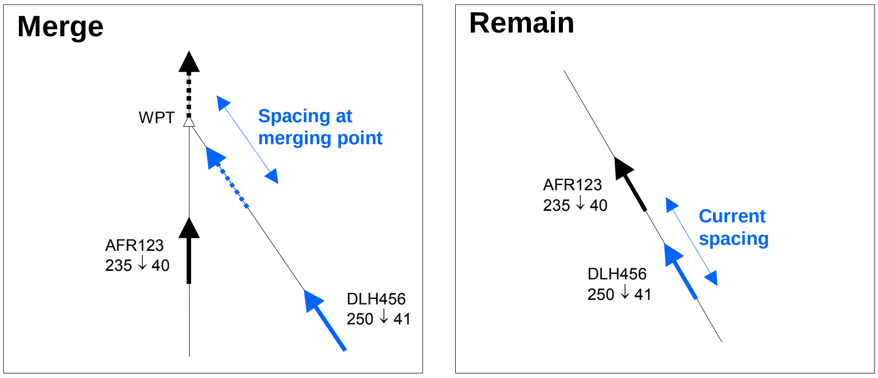

Figure 4: Merge and remain applications.

In time-based spacing, the required spacing value is constant (90s) throughout flight phases. In distance-based spacing, a modification of the required spacing value occurs in the final approach phase. The spacing instruction changes from "Remaining exactly 8NM behind" to "Remaining at least 5NM behind".

December'02 experiment showed that under nominal conditions spacing tolerances of 1NM and 0.5NM were found feasible by pilots. The 0.25NM tolerance seemed more difficult and required more effort and attention. Therefore, it was decided to fix the spacing tolerance at ±0.5NM for distance-based spacing. Given the speed range of the aircraft in the scenarios (from cruise to FAF), an equivalent margin of tolerance for time-based spacing was set at ±5 seconds.

To ensure a smooth and stable behaviour (in particular with multiple aircraft in a sequence) and avoid many speed adjustments, the pilot shall acquire the spacing when the target passes the merging point. The suggested airspeed is computed so as to meet the desired spacing objective.

When "remaining at least 5 NM behind", the crew has no time constraint to achieve a given spacing but should only ensure that the spacing value is not increasing and that the minimum spacing (e.g. 5 NM) is not infringed. As long as the speed selected by the crew meets those criteria, no further speed guidance is necessary and the suggested airspeed will match the value of the selected speed.

As in December'02, particular attention was paid to the influence of the descent mode on the deceleration of spacing instructed aircraft. Given the fact that flight arrivals are simulated, most speed adjustments are decelerations occurring in descent. To control the number of experimental variables, it was decided to harmonise the descent profiles among crews:

- Pilots were asked to systematically use an "open descent" mode (priority to speed);
- The use of speed brakes was accepted to ensure realism in the simulation.

In addition, it should be stressed that pilots were not authorised to modify route or change altitude, unless explicitly instructed by the controller.

4.6. FLIGHT CREW TASKS

Flight crew tasks were the same as in December'02. The flight crew was tasked to fly the simulator through the autopilot together with usual tasks, namely communications with ATC, fuel check, ATIS, arrival preparation and briefing and checklists. The scenario consisted in maintaining a given spacing in a “merge” situation, through adjustments of the selected speed on the flight control unit (FCU) with the support of display cues. It should be noticed that there was no managed spacing mode. Concerning the flight task distribution, following today’s practices, it was suggested that the PNF would perform the input of data in the Multipurpose Control Display Unit (MCDU) and that the PF would make the necessary speed adjustments to perform the spacing task. Both pilots would monitor the spacing.

During runs with spacing task, the target aircraft was under conventional control (i.e. not spacing instructed). ATIS, charts, checklists and operational flight plans were provided.

4.7. SIMULATOR AND PILOT INTERFACE

Figure 5: Cockpit Simulator.

The cockpit simulator is an Airbus A320 FMGS trainer (from FAROS) allowing to perform automatic flight, with captain and first officer positions (Figure 5). It is composed of the following standard elements: Primary Flight Display (PFD), Navigation Display (ND) including a simplified TCAS display, Multipurpose Control and Display Unit (MCDU), Flight Control Unit (FCU), throttles and a simplified Electronic Centralised Aircraft Monitor (ECAM) with Engine Display only. No external view is available.

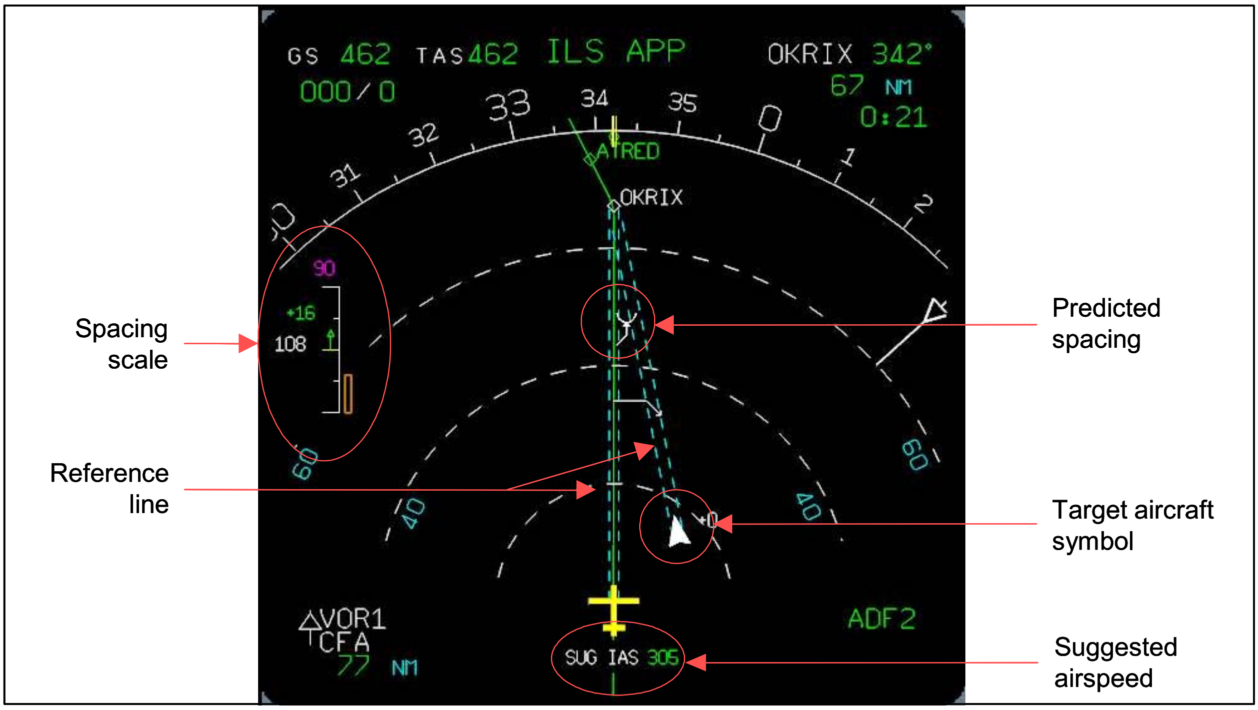

Figure 6: ASAS features on ND.

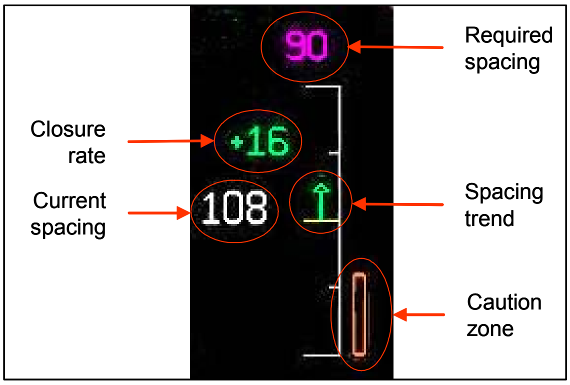

Figure 7: Spacing scale.

In addition to these standard elements, new features (denoted ASAS) have been developed to support the spacing task. These features are new MCDU pages for data input, and new graphical indications on the ND to visualise the target and allow the pilot to perform the necessary speed adjustments. The majority of new features originate from pilot suggestions evoked during the previous experiment. On the ND, the ASAS features are (Figure 6):

- **Target aircraft**: The head of the target symbol (triangle) represents the position of the target and the symbol is pointing in the direction of the target heading. The associated data tag provides information on the relative altitude (e.g. –26 for 2600ft below) and on the vertical trend of the target (e.g. ↓ for descending).

- **Reference line**: To highlight the current spacing situation ("merge" versus "remain"), a reference line (double dashed line) links ownship and target aircraft via the merging point in a "merge" situation and through own trajectory in "remain" when under lateral navigation or directly in "remain" when under heading selected.

- **Predicted spacing**: A broken arrow with an arc ( ) indicates the position where the spacing will be acquired.

- **Spacing scale:** Positioned on the left of the ND, it indicates: current and required spacing, spacing trend, closure rate, and tolerance margin (Figure 7). It is centred on the current spacing value (yellow line) with lower spacing values at the top of the scale and higher spacing values at the bottom. The range of the scale represents twice the tolerance margin (2×0.5NM for distance-based spacing and 2×5 seconds for time-based spacing). The current spacing value is indicated in seconds at the left of the scale (e.g. 108). The required spacing is materialised by a magenta symbol (triangle) when within scale range, and by the textual value (displayed either at the top or the bottom of the scale depending whether it is smaller or larger than current spacing) when outside range. The closure rate, the equivalent indicated airspeed (IAS) in knots, is indicated in green (e.g. +16 for same altitude) and the spacing trend (green arrow) graphically represents projected spacing in 30 seconds. It is pointing downwards if ownship goes slower than the target and upwards if it is goes faster. Increasing the speed will make the trend vector point further upwards. The limits of tolerance margin (caution zone) are represented by amber rectangles. When the current spacing gets out of the tolerance (i.e. required spacing symbol out of the spacing scale), caution situation is detected.

- **Suggested airspeed:** Displayed at the bottom of the ND, the suggested IAS corresponds to the speed that one should take in order to acquire and then maintain the required spacing.

  Since December'02, colour coding and blinking have been introduced. When a difference of more than 7kt between current and suggested IAS is detected, the suggested IAS blinks. The suggested speed is displayed in green when feasible. Nevertheless, it is displayed in amber when the use of flaps becomes necessary and in red when its value gets outside the flight envelope.

- **ND system pilot prompts:** Depending on situations, specific ASAS advisory caution or warning messages may be displayed as pilot prompts at the bottom of the MCDU and the ND. The five prompts were:

  - 'ASAS STABILISE SPEED' (advisory),
  - 'ASAS ACCELERATE' (advisory or caution),
  - 'ASAS SLOW DOWN' (advisory or caution),
  - 'ASAS DIR TO' (advisory),
  - 'ASAS UNABLE DELEGATION' (warning).

All features are identical in distance and time-based spacing (except for the units). Tolerance margins were set to ±0.5NM or ±5s for caution and to ±1NM or ±10s for warning.

ADS-B capabilities were simulated. Target state vectors (position and velocity) were transmitted periodically (every 5 seconds) and received onboard the cockpit simulator.

All ASAS features were identical to the ones define for December'02 except the prompts "ASAS ACCELERATE" and "ASAS SLOW DOWN" which replaced the "LOSING SPACING" prompt following pilots' suggestions. For an extended description of the interfaces, see Pilot handbook (CoSpace 2003).

4.8. LINK WITH PAST EXPERIMENTS

June'03 experimental conditions are summarised in Table 7. To understand what evolved and what remained constant between successive experiments, experimental conditions defined for previous experiments are presented.

Table 7: May'02, December'02 and June'03 experimental conditions (items in blue and bold indicate changes from the previous experiment).

	May'02	December'02	June'03
Flight phase	Cruise to Initial Approach Fix	Cruise to Initial Approach Fix	**Cruise to Final Approach Fix**
Type of spacing	Distance based	Distance based	**Time based and distance based**
Baseline	No	Yes	Yes
Spacing instruction	Remain, merge, heading then merge	Merge	Merge
Spacing tolerance	±1NM	±0.25NM, ±0.5NM and ±1NM	**±0.5NM and ±5s**
Position in chain	Aircraft #2	Aircraft #2	Aircraft #2
Number of spacing instruction per flight	1	1	1
Issue of spacing instruction	In cruise or in descent	In cruise	In cruise
Destination	1 airport	2 airports	2 airports
Severity conditions	Nominal No wind	Nominal No wind	Nominal No wind
Spacing guidance cues	Current spacing value	Spacing scale Suggested airspeed	**Modified spacing scale** **Modified suggested airspeed** **Advisory messages**
Simulation environment	**Cockpit:** part task, no external view	**Cockpit:** part task, no external view	**Cockpit:** part task, no external view
	Traffic: target only	**Traffic:** all surrounding traffic	**Traffic:** all surrounding traffic
	ATC: instructions to flight crew only	**ATC:** instructions to flight crew and all traffic in sector	**ATC:** instructions to flight crew and all traffic in sector

5. DATA COLLECTION, PRE-PROCESSING AND ANALYSIS

5.1. DATA COLLECTION

For measurement purposes, two groups of data (objective and subjective) were collected.

- Objective data consisted of system recordings, including aircraft parameters, pilots' actions and spacing parameters (e.g. spacing value).
- Subjective data consisted of observers' notes, questionnaires, including the use of the NASA Task Load Index (NASA-TLX) for workload assessment, debriefing items.

Data collection method, occurrence, relevance and attributes are summarised in Table 8: Blank questionnaires are presented in annex 3.3 and 3.5 and the system recordings are presented in annex 4.

Table 8: Data collection method and data attributes.

Occurrence	Method/tool	Metrics concerned	**Attributes** Subjective/Objective Qualitative/Quantitative
Pre simulation	Questionnaire	None (pilots profile)	Subjective/Objective Qualitative
Run Continuous	Observations	All human shaping factors, cues about human activity, efficiency and safety	Subjective (observer bias) Qualitative
	System recordings	All, at a detailed level	Objective Quantitative
Post run	Questionnaire	All, at a detailed level	Subjective Qualitative/Quantitative
	NASA-TLX	Some shaping factors (workload)	Subjective Quantitative
Post simulation	Questionnaire	All, at a detailed level	Subjective Qualitative/Quantitative
	Debriefing	All	Subjective Qualitative

5.2. DATA PRE-PROCESSING

5.2.1. Period of analysis

Data were pre-processed to restrict the analysis to a comparable period for all runs.

The period of analysis starts with the beginning of the "acquisition" phase, i.e. when the pilot validates the spacing instruction.

The end of the period of analysis is related to the "Cancel spacing" instruction. As this instruction was given at slightly different times, in each condition (runs with same destination, same type of spacing and same initial spacing deviation), the end of the period of analysis corresponds to the end of the shortest "remain" phase.

To ensure that all runs were stabilised at the end of the defined analysis phase, it was checked that the closure rate was small (±10kt) and the spacing deviation was within spacing tolerance in runs with time-based spacing (Figure 8)[3]. Concerning runs with distance-based spacing, only closure rate was retained as a stability criterion due to the fact that with an instruction to "Remain at least 5NM behind", the spacing deviation criterion is not relevant. At the end of the analysis phase, the closure rate was small in all distance-based runs.

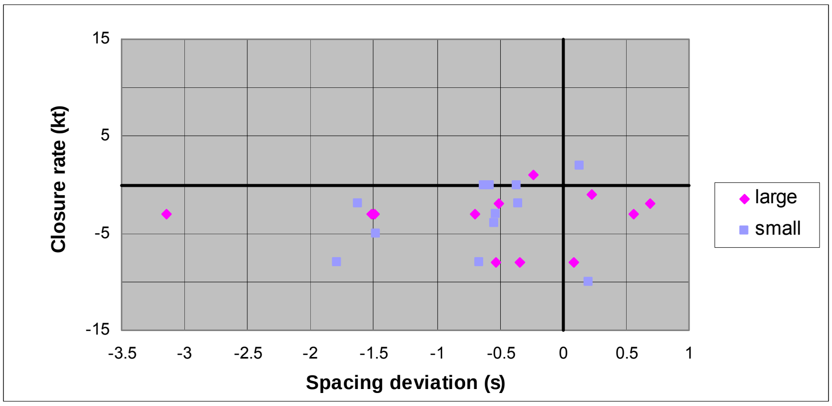

Figure 8: Relationship between closure rate and spacing deviation in time-based spacing at the end of analysis phase.

With this exit condition, the duration of the periods of analysis ranged from 20min 54s to 27min 30s for the LFPG scenario and from 25min 13s to 26min 27s for the LFPO scenario. Details about run durations are presented in annex 5.

5.2.2. Data Verification

Prior to analysing data recorded during simulation runs, a verification process took place.

First, it consisted in filtering jumps in values clearly identified as system bugs (Figure 9). Some of the bugs were due to irregularities in the aircraft plots (DIS time-stamps); others to system calculations occurring simultaneously when passing a waypoint. In all cases, they were fugitive and did not impact pilot actions.

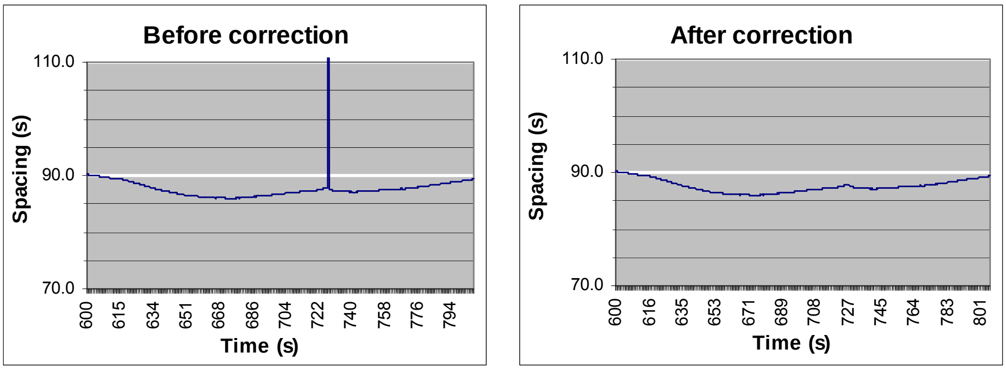

Figure 9: Example of jump in values before and after correction.

[3] If not, runs would have been removed from data analysis.

Other types of problems impacting the raw data for a longer duration were encountered during simulation: a temporal jump due to a network problem and unexpected pilot actions (4 pull heading and 1 incomplete flight plan entered in the FMGS) causing wrong calculations. Nevertheless, those problems were clearly identified as such by the crews and did not impact their management of the spacing task.

To handle those problems and make the runs analysable (e.g. average, max value), it was decided to delete the data related to the spacing value and suggested airspeed, rather than trying to interpolate the data. An example of data deletion is presented in Figure 10.

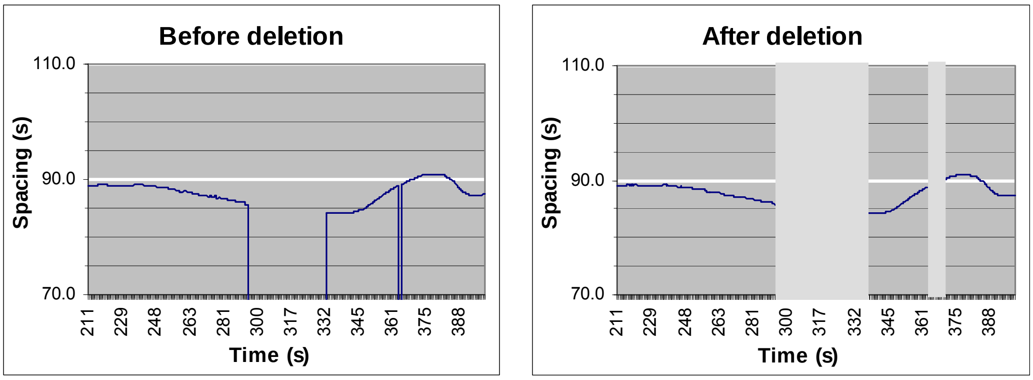

Figure 10: Example of calculation problem (due to a "pull heading" action) before and after deletion of the spacing value.

Finally, in distance-based spacing between the cancellation of "Remaining exactly 8NM behind" and the start of "Remaining at least 5NM behind", data related to the spacing value and the suggested airspeed were not relevant. Consequently, these data were deleted from the log files.

5.3. DATA ANALYSIS

Analyses were conducted on data taking into consideration the type of spacing task, the initial spacing conditions for time-based scenarios and the function (PF, PNF). Furthermore, it was checked during the analyses that scenarios (LFPO, LFPG) had no impact on the results.

The objective analyses consisted in two parts:

- A quantitative analysis corresponding to automatic processing of relevant data to provide statistical figures.
- An operational expert analysis to help understanding flight events, corresponding to a qualitative analysis.

The subjective analysis consisted of the synthesis of debriefings, observers' notes and answers to questionnaires.

6. RESULTS

This section presents the results of data analysis. It is organised as follows:

- Part 1 describes collected data.
- Part 2 summarises comments on design and feasibility.
- Part 3 presents data related to the high level objective “human shaping factors”.
- Part 4 presents data related to the high level objective “flight crew activity”.
- Part 5 presents data related to the high level objective “effectiveness”.
- Part 6 presents data related to the high level objective “safety”.

6.1. FACTUAL DATA

Eight runs per session, for 6 crews, were initially planned (Table 9). Due to limited availability of pilots, half of the crews did not perform the two runs with distance-based spacing. As a result, 42 runs out of 48 planned were actually measured.

As runs without spacing were considered as reference runs for pilots, their analysis focused on subjective data collected in post-run questionnaires and through pilots’ comments. Moreover, given the limited number of runs with distance-based spacing, their analysis also dealt with subjective data. A full data analysis was completed for runs with time-based spacing.

The 12 pilots filled in the pre- and post-simulation questionnaires and participated in the debriefing sessions. Filled questionnaires are presented in annex 3.4 and 3.6.

Table 9: Planned, measured and analysed runs.

Condition	Planned	Measured	Analysed	
			Post-run questionnaire	Observations and system recordings
Without	12	12	12	-
Distance	12	6	6	-
Time with large initial spacing deviation	12	12	12	12
Time with small initial spacing deviation	12	12	12	12

6.2. DESIGN AND FEASIBILITY

Simulation realism

The overall simulation environment was considered realistic by all pilots. However, pilots pointed out that workload generated by usual flying task was lower in our part-task simulation environment than in real flight. Suggestions were made as well: adding an intercom between pilots could enhance audio aspects and involving controllers in real-time rather than using recorded files might increase realism.

Suggestions for future experiments

Suggestions concerned more complex scenarios with potential change of elements (target, merging point, runway and airport). Regarding conventional flying tasks, realism of scenarios should be enhanced (e.g. including meteorological problems, more difficult approach procedure, TCAS, small technical failures…). Using a full-flight simulator would help to increase realism and behave as if in real flight. Moreover, pilots thought they should be entitled to use various descent modes to manage their vertical profile.

6.3. HUMAN SHAPING FACTORS

6.3.1. Motivation and Perceived Usefulness

Most pilots considered the spacing task as quite or totally motivating, not really stressful and quite or totally compatible with usual flying tasks despite an increase of mental effort.

Perceived benefits

The benefits perceived by pilots are:

- a better anticipation of actions resulting in a better flight management and an earlier preparation of the aircraft for the approach phase,
- fewer heading instructions resulting in less variations in trajectories,
- fewer speed instructions,
- accurate spacing control,
- a better understanding of surrounding traffic,
- less communications with ATC.

Moreover, some pilots mentioned two specific benefits of airborne spacing:

- it might be beneficial in case of communication failure,
- it could eliminate circular holding.

Perceived limitations

It is generally felt that the spacing task could not be performed under bad weather conditions (turbulence, cumulonimbus).

Even though pilots felt that the spacing task was acceptable with current information displays, as in previous experiments, most of them requested a managed spacing mode, the speed-select mode being appropriate only as a fallback mode.

For future simulations, pilots were eager to assess airborne spacing in long chains of spacing instructed aircraft and in more complex scenarios with potential change of elements (target, merging point).

Time-based spacing Vs distance-based spacing

Time-based spacing was felt easier to handle than distance-based spacing. The reason given was a better anticipation of target behaviour thanks to the time delay and then fewer speed actions to perform.

6.3.2. Workload

Debriefing

Generally, pilots thought that the spacing task enabled a better distribution of workload between controllers and pilots. Moreover, they felt a real gain in terms of communication. However, workload seemed increased (especially for PF) but still acceptable in our part-task environment. Pilots also mentioned that cancellation of the spacing instruction when intercepting the localizer and the glide slope increased workload in a phase already critical. Hence, they wondered whether the increase of workload due to the spacing task would still be acceptable in a more realistic environment (e.g., full flight simulator, operational events).

NASA TLX rating

Pilot workload was mainly assessed through the NASA-TLX, which addresses 6 dimensions. **Mental demand**, **temporal demand**, **physical demand**, **frustration** and **effort** remained at an acceptable level in all conditions for both PF and PNF. **Performance** was rated high in all conditions for both PF and PNF (Figure 11).

Compared to runs without the spacing task, mental demand was slightly higher in runs with time-based spacing for both PF and PNF, and in runs with distance-based spacing for PF only. Temporal and physical demands were generally slightly stronger for PF across all conditions. Moreover, they were slightly stronger in runs with time-based and distance-based spacing than in runs without the spacing task. However, those averages should be interpreted cautiously as dispersion was quite large. Frustration and effort were more important for PF except in runs with time-based spacing. Time-based spacing seemed to be more effortful and frustrating for PNF compared to the other conditions. Again those averages should be interpreted cautiously as dispersion was quite large. Performance was perceived as equivalent in all conditions by both PF and PNF.

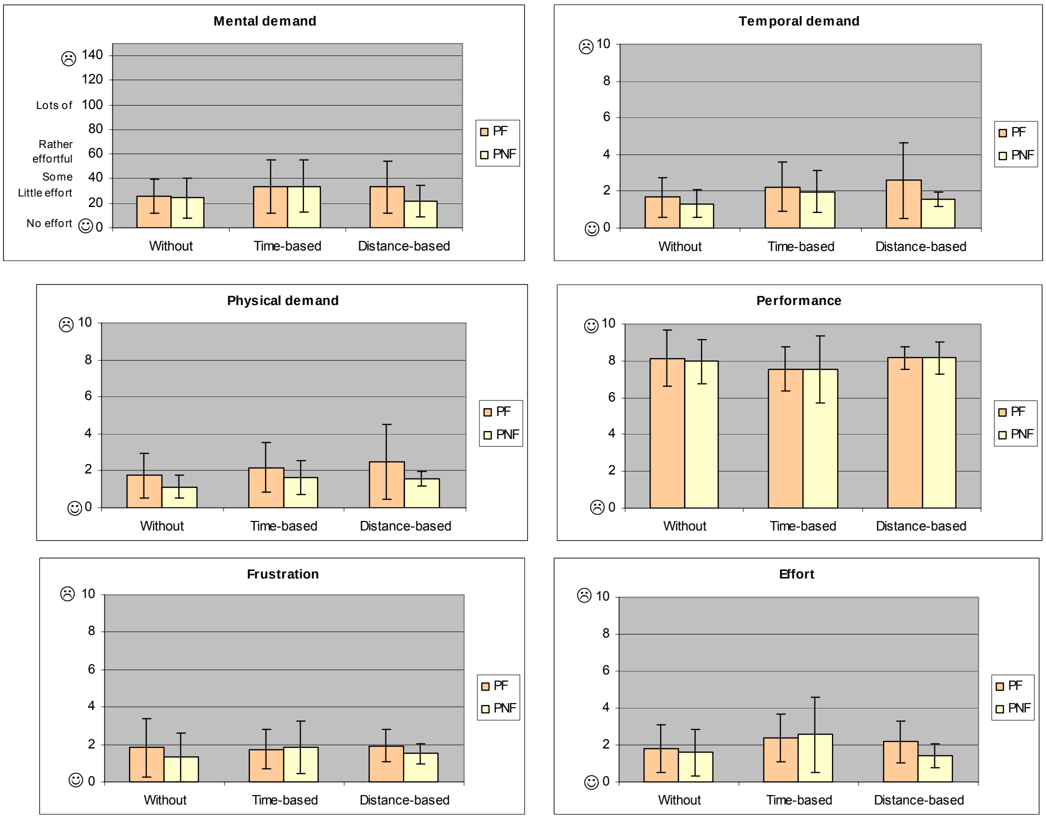

Figure 11: NASA-TLX scores.

Communication load

Communication load should address both communications with ATC (number, frequency and duration of R/T messages) and communications in the cockpit (number, frequency and duration of exchanges). However, due to technical limitations, communications were not recorded. Only observer notes and questionnaire items gave information about the communication load[4].

Regarding communications with ATC, most pilots felt that messages were less frequent with the spacing task both in the initial descent and in the approach phases. Moreover, messages are either less time-critical or same as today in both phases. No clear trend emerged from pilots' answer about message length in initial descent phase, whereas in approach phase messages are either shorter or same as today.

Regarding communications in the cockpit, 50% of the pilots perceived a positive impact of the spacing task whereas 30% of the remainders perceived no difference and 15% perceived a negative impact for both PF and PNF.

Monitoring load

Regarding monitoring, half of the pilots perceived a more demanding visual scanning task due to ASAS cues displayed on the ND whereas the others perceived no difference.

[4] Quantitative analysis of communications with ATC would be more appropriately carried out in ground experiments where sufficient data could be collected.

6.3.3. Usability

Usability was mainly assessed through pilot comments during the experiment and questionnaire items.

Tool

Pilots who had participated in the previous experiment (December'02) considered ND modifications as improvements and new comers rated information displays (ND and MCDU) as good or excellent. The suggested IAS was much appreciated but its calculation was too accurate and sensitive. The advisory delivered by the blinking suggested IAS was good but should be more alerting. The spacing scale appeared to be still a bit overloaded. The usefulness of the closure rate and the amber caution zone was questioned. However, the spacing trend was appreciated. The MCDU was well accepted to enter ASAS data.

Concept

Pilots made three comments on applicability conditions: 1) the spacing task could be continued after the IAF but the moment when to stop it should be carefully defined; 2) it was not clear whether a change of target and a new instruction could be performed under FL100; and 3) in distance-based spacing, it was felt that the transition to the approach phase would be difficult to manage by controllers on congested airports (uncertainty on the evolution of the spacing value following a "remain at least 5NM behind" instruction).

6.3.4. Synthesis on Human Shaping Factors

The overall feedback was positive. The spacing task was motivating and perceived as quite compatible with usual flying tasks despite an increase of mental effort which remained acceptable in the part-task simulation environment. Perceived benefits were: better understanding of the situation and anticipation, lower communication load due to less frequent exchanges with controllers. Time-based spacing was felt easier to handle. Even though information displays were appreciated, some pilots asked for a managed spacing mode.

6.4. FLIGHT CREW ACTIVITY

The present analysis focused on the performance of the spacing task itself in terms of spacing acquisition and maintenance. Investigation of the impact of the spacing task on other flight crew tasks will be carried out in the object of future experiments.

6.4.1. Subjective Feedback

All pilots considered the spacing task easy to handle in initial descent and in approach phases. The spacing task required many speed adjustments (~15) but pilots noticed that a speed adjustment required only 2 actions (speed action, crosscheck) whereas a speed instruction from the controller required 4 actions (instruction, read back, speed action, crosscheck). Their feeling was that adjustments of the selected speed were acceptable but should be kept only as fallback of a managed spacing mode. Moreover, it was not clear whether situation awareness was improved. According to one pilot, the situation awareness could be worse (focus on the target to the detriment of primary flight parameters or TCAS traffic) whereas another pilot thought he had a clear view of the situation and it was easier to understand changes in the situation.

Time-based was generally preferred to distance-based. It created a 90 seconds history and reduced the number of speed actions and the use of speed brakes. Also, it did not require modifying the spacing value when transferred to the approach.

6.4.2. Phase Duration

The spacing task is first described in relation with flight phases and events to assess its impact on pilot activity.

The first analysis consisted in assessing the time spent in acquiring spacing during the "merge" phase. The objective was to check whether flight crews followed the constraint that was to acquire it when the target was over the merging waypoint. In December'02, the "acquisition" phase ended when the spacing deviation was within the spacing tolerance. However, as the spacing acquisition continued once within the spacing tolerance, a more appropriate criterion was chosen: the spacing deviation had to be below 3 seconds and the closure rate near 0 (±2kt)[5] to consider it ended. The mean acquisition phase duration was 87% of the "merge" phase with a large initial spacing deviation and 62% with small initial spacing deviation (against respectively 91% and 71% if the suggested airspeed was closely followed). Pilots tended to acquire the required spacing sooner when the initial spacing deviation was small. These results led to split the "merge" phase into two distinct phases for analysis purposes: the "acquisition" phase and the "maintain" phase.

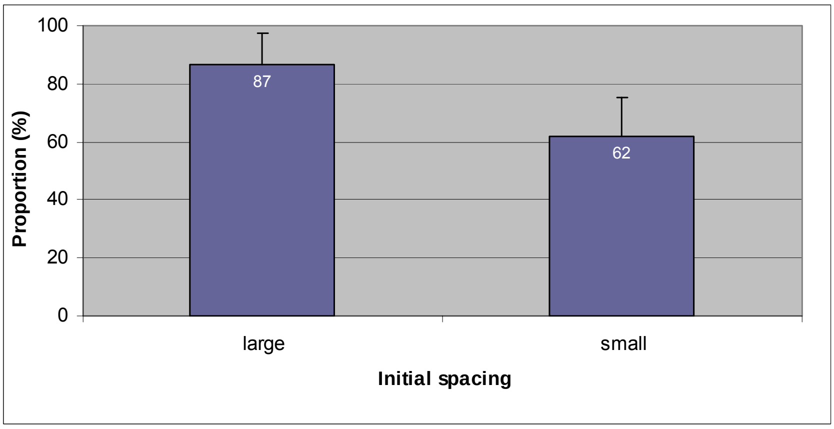

Figure 12: "Acquisition" phase duration compared to the "merge" phase.

Similar results are observed when comparing the distribution of "acquisition" phase duration for each scenario (Figure 13). The initial spacing deviation influenced the duration of the "acquisition" phase: between 70% and 100% of the "merge" phase in runs with a large initial spacing deviation and between 30% and 80% in runs with a small initial spacing deviation.

Due to the change of criterion, the "acquisition" phase lasted longer than in December'02 (from 35% to 65% of the "merge" phase).

[5] If those conditions are not met when the target passes the merging waypoint, the "acquisition" phase ends at that point provided the spacing deviation is within the spacing tolerance.

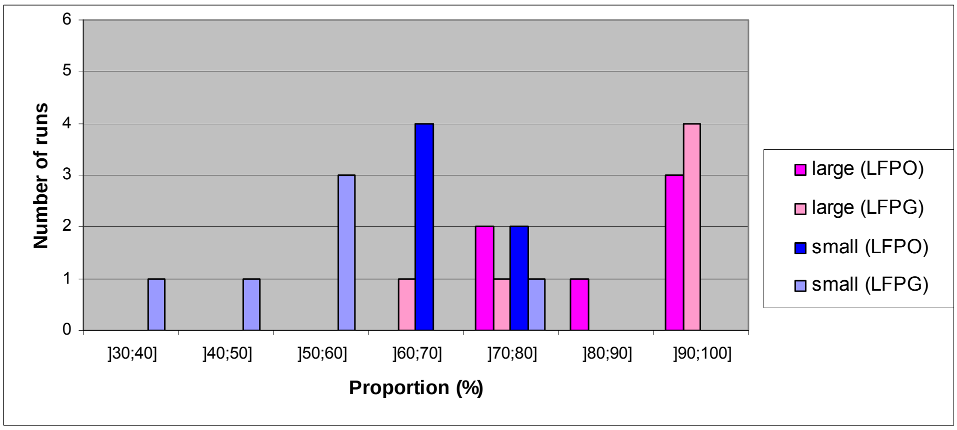

Figure 13: Distribution of "acquisition" phase duration compared to the "merge" phase.

6.4.3. Speed Profiles

Typical speed profiles are presented for illustration (Figure 14 to Figure 17). Selected, current and suggested airspeed are displayed. In addition, spacing phases, own TOD, target speed reduction and target descents are marked. Speed profiles for every run are presented in annex 6.

Changes in the selected airspeed represent pilots' speed actions on the FCU. In the May'02 flight deck experiment (CoSpace 2004b), one speed action was defined as a succession of speed changes with less than 5 seconds between two speed changes.

Globally, the speed profiles show that flight crews follow the suggested IAS. In some cases, the flight crew may slightly over react, as for example in Figure 14 where the flight crew slows down more than suggested by the system. The offset between the suggested IAS and the current speed varies as a function of the pilot reaction time to follow the suggested IAS.

Looking closer at the speed profiles, it appears that:

- The number of speed actions may vary greatly from one crew to another for similar speed profiles (e.g., 20 speed actions in Figure 15 and 8 speed actions in Figure 17).
- The frequency of speed actions is not regular; a long period without any speed actions may be followed by many consecutive actions.
- The temporal distribution of the speed actions seems to be related to the changes in the target state.
- The magnitude of speed actions may vary from very small speed adjustments (e.g. 2kt) to large ones (e.g. 40kt).

These aspects are analysed more closely in the next paragraphs.

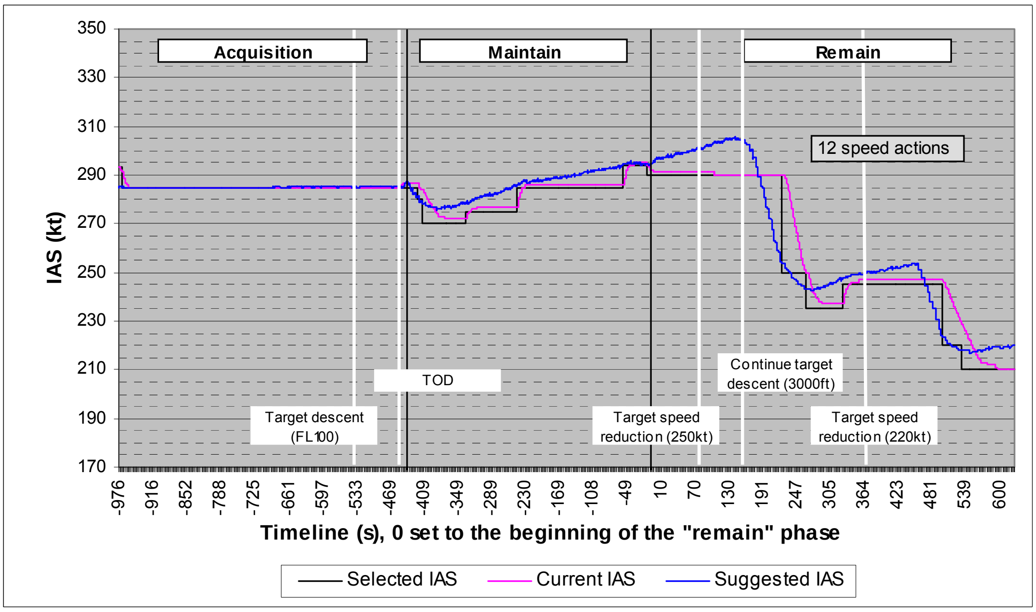

Figure 14: Example of a speed profile for a LFPG scenario with a small initial spacing deviation.

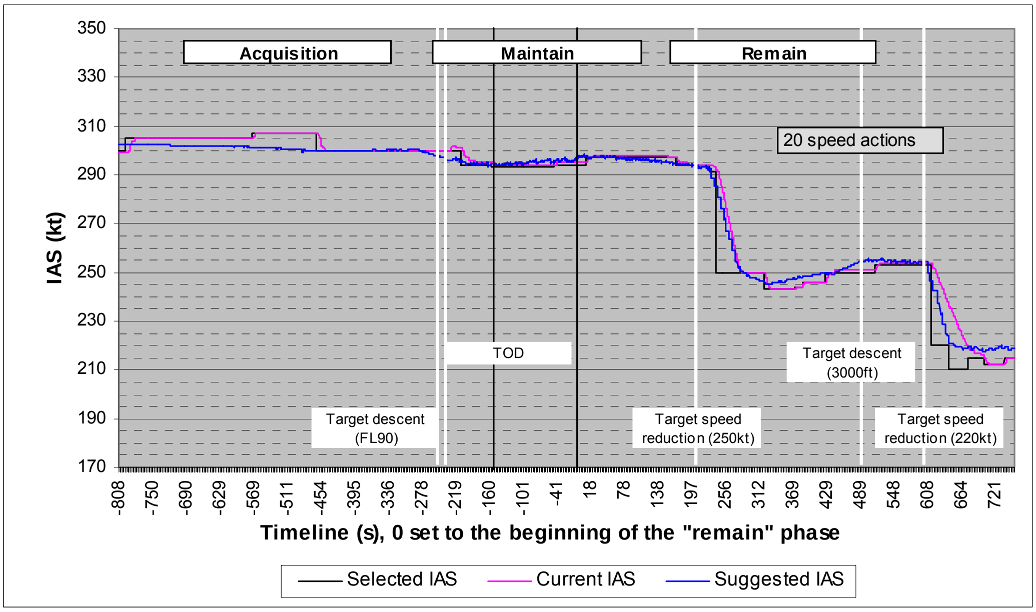

Figure 15: Example of a speed profile for a LFPO scenario with a small initial spacing deviation.

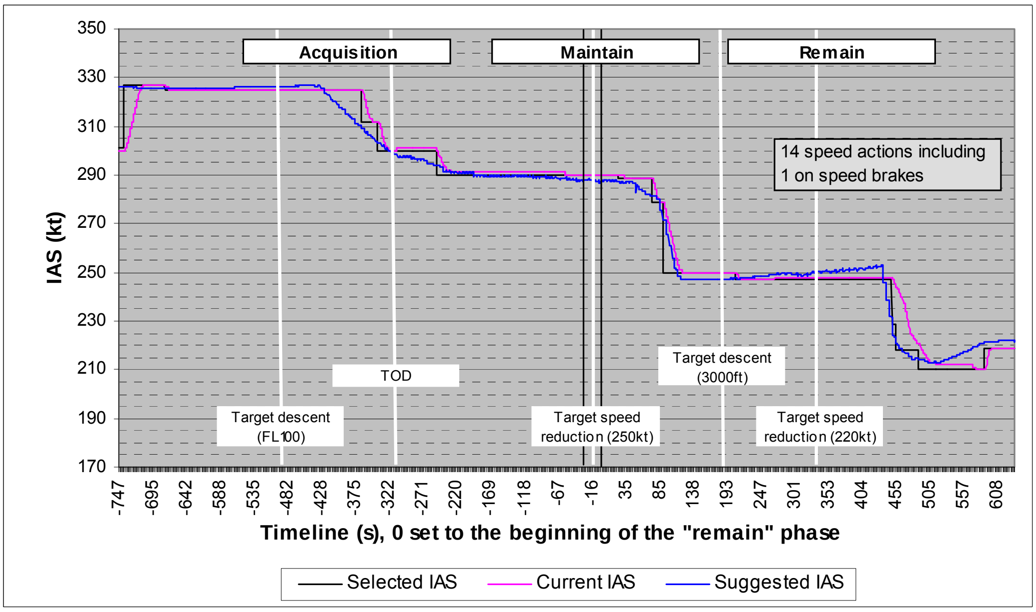

Figure 16: Example of a speed profile for a LFPG scenario with a large initial spacing deviation.

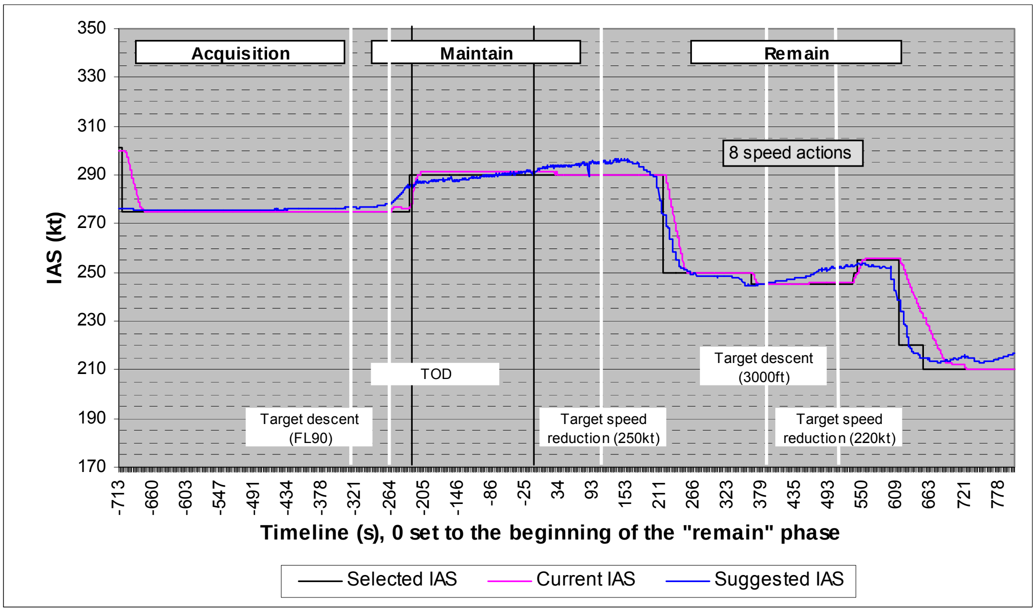

Figure 17: Example of a speed profile for a LFPO scenario with a large initial spacing deviation.

6.4.4. Number of Speed Actions

The analysis of the number of speed actions per minute showed no strong difference was observed between conditions (Figure 18): on average, 0.8 speed action was performed per minute. Results are similar in LFPO and LFPG scenarios.

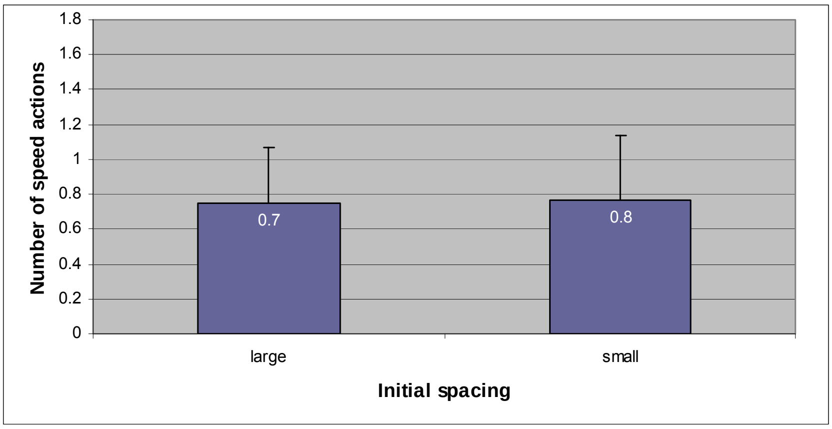

Figure 18: Average number of speed actions per minute.

As in the previous experiment, the analysis of the number of speed actions per minute in each spacing phase (Figure 19) showed that the "remain" phase was the most demanding in terms of the number of speed actions whereas the "acquisition" phase was the least demanding. In the "acquisition" phase, speed actions mainly aimed at acquiring the desired spacing whereas in the "maintain" and "remain" phases, speed actions are mainly triggered by changes in target state. The same trend was observed for small and large initial spacing deviations. In average, more speed actions were performed in the "merge" phase when the initial deviation was small compared to runs with a large initial spacing deviation. However, the analysis of the relation between the "acquisition" phase duration and the number of speed actions performed during the "merge" phase shows no clear trend. Consequently, the hypothesis that shorter "acquisition" phase would lead to more numerous speed actions during the "merge" phase is not confirmed (Figure 20). This result reflects the large dispersion observed in average speed actions per minute. An effect of scenario was noticed as well: less speed actions were performed in the "merge" phase in LFPO scenarios.

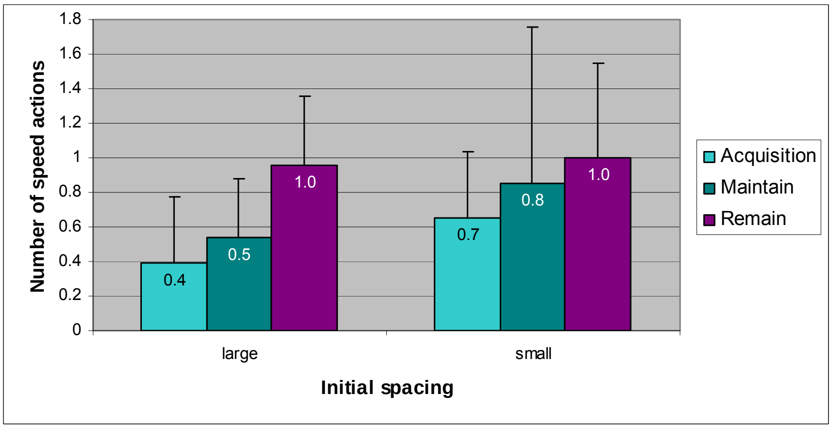

Figure 19: Average number of speed actions per minute as a function of the spacing phases.

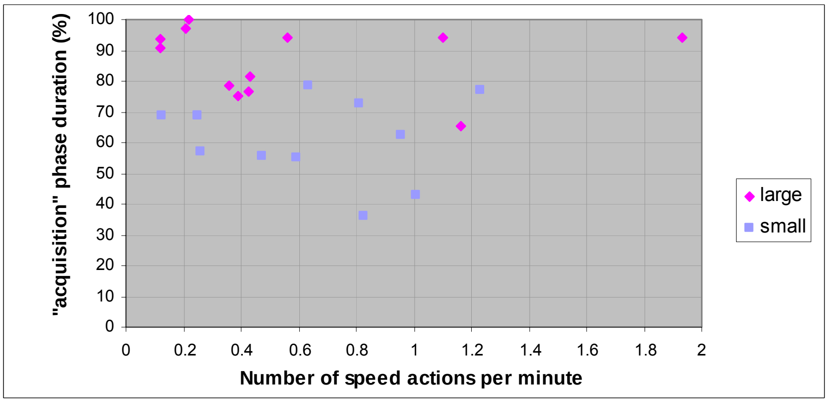

Figure 20: Relationship between "acquisition" phase duration and number of speed actions during the "merge" phase.

6.4.5. Frequency of Speed Actions

Beyond the number of speed actions, the average period between successive speed actions was analysed. Five seconds was considered as the minimum period between two actions (see annex 7.1 for examples of temporal distribution of successive speed adjustments). Below 5 seconds, successive speed adjustments are considered as one action. The results (Figure 21 and Figure 22) show that the initial spacing deviation had no impact on the distribution of periods: most actions were separated by small periods (less than 1 minute). However, longer periods were observed as well. Similar results were observed in LFPO and LFPG scenarios (see annex 7.2).

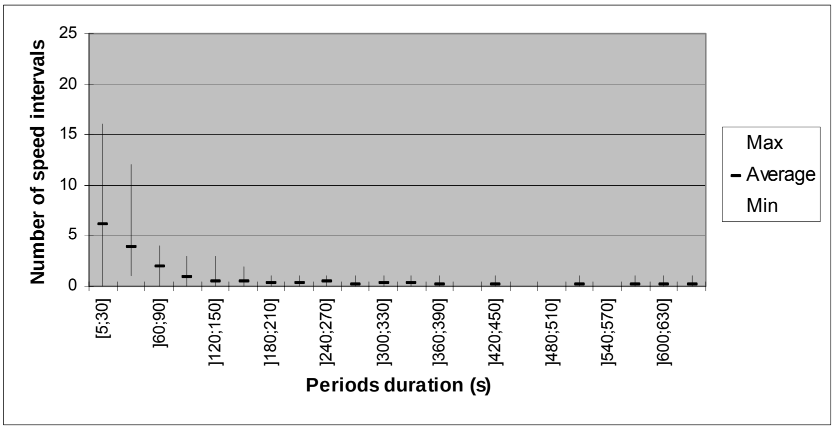

Figure 21: Distribution of periods between successive speed actions in the large initial spacing deviation condition.

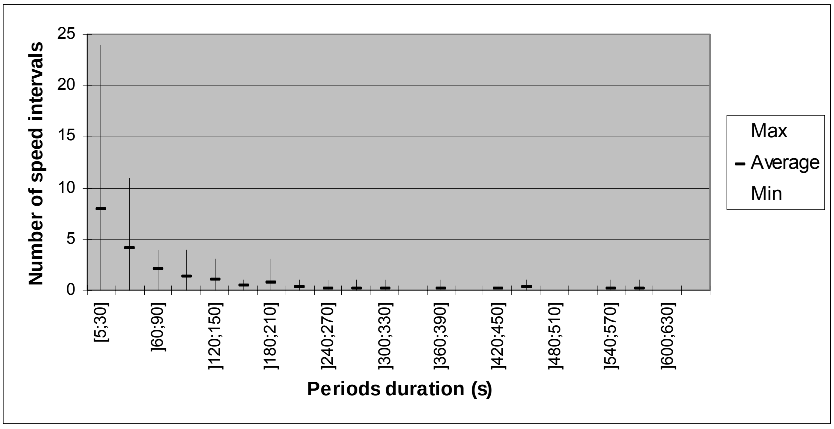

Figure 22: Distribution of periods between successive speed actions in the small initial spacing deviation condition.

6.4.6. Temporal Distribution of Speed Actions

To relate speed actions to flight phases and main changes on target state, the temporal distribution was analysed (Figure 23 to Figure 26). Speed actions performed at the beginning of the "acquisition" phase aimed at acquiring the spacing. The other speed actions were triggered by changes in target state and aimed at maintaining the spacing (target descent to FL090 or FL100, target speed reduction to 250kt, target descent to 3000ft and target speed reduction to 220kt). The last three changes occurred in the "remain" phase. This explains the higher number of speed actions performed in this phase.

This shows that acquiring and maintaining the spacing required groups of speed actions spread over the spacing task and directly related to changes in target state. On the contrary, in conventional ATC, one speed instruction requires one single speed action. Further enhancements of the suggested airspeed may help to reduce the number of speed actions in each group.

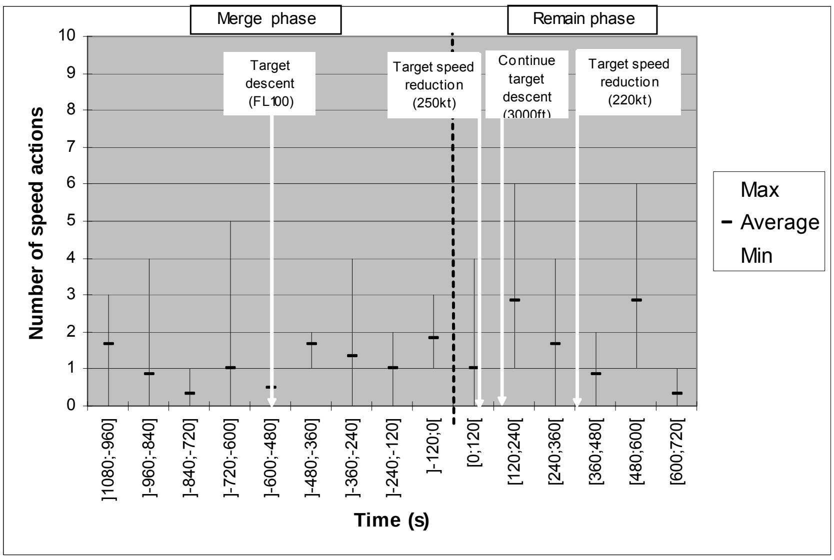

Figure 23: Temporal distribution of speed actions for a LFPG scenario with a small initial spacing deviation.

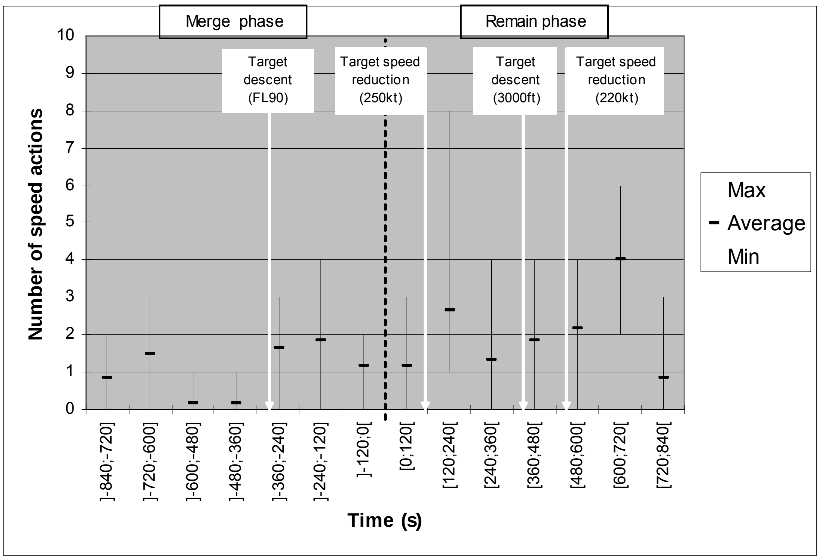

Figure 24: Temporal distribution of speed actions for a LFPO scenario with a small initial spacing deviation.

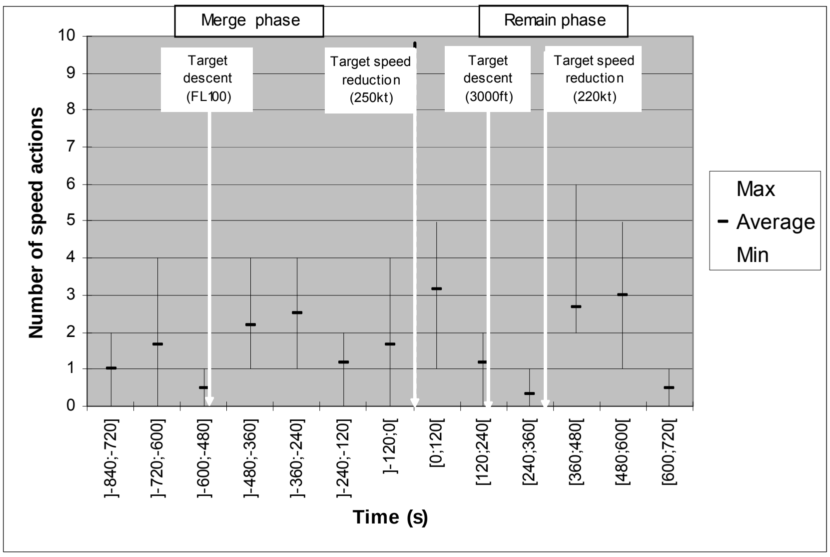

Figure 25: Temporal distribution of speed actions for a LFPG scenario with a large initial spacing deviation.

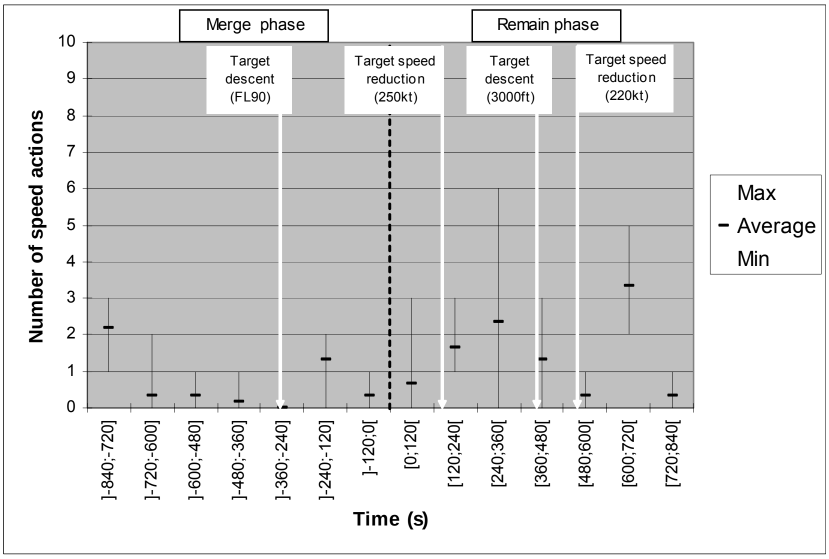

Figure 26: Temporal distribution of speed actions for a LFPO scenario with a large initial spacing deviation.

6.4.7. Magnitude of Speed Actions

To assess the impact of the spacing task on speed magnitude, the total magnitude of speed reduction between the beginning and the end of the analysis phase was first considered. Total magnitude figure included both speed increase and decrease. The analysis of the total magnitude of speed actions (Figure 27) shows that there is an inter-individual effect, as for a same scenario with the same initial spacing deviation, large differences are noticed. Moreover, no impact of the initial spacing deviation on the total magnitude can be showed as in the two scenarios with large initial spacing deviation, the average total magnitude is either lower or higher than in the scenarios with small initial spacing deviation.

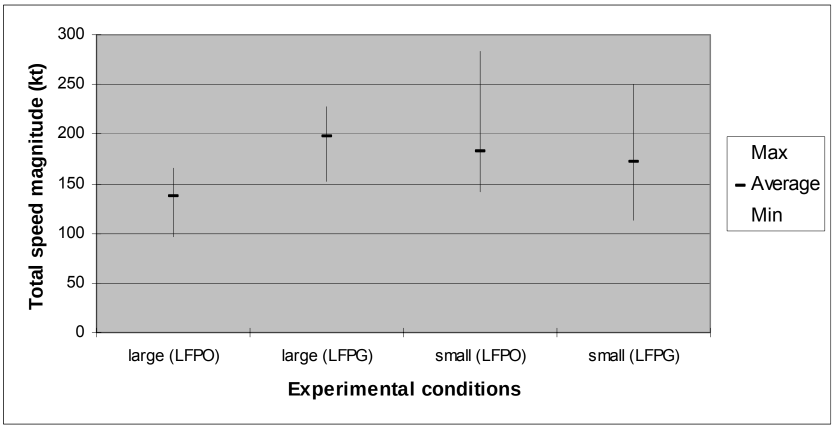

Figure 27: Total magnitude (absolute values) of speed actions.

Beyond the total magnitude of speed actions per condition, the magnitude of each speed action was analysed. The average speed magnitude corresponds to small adjustments slightly above 10kt (Figure 28) but standard deviations indicate a rather noticeable dispersion. Further analysis is required to understand what caused these larger speed changes (see 6.5.3.). In runs with small and large initial spacing deviation, the average speed magnitudes are almost the same (respectively 11kt and 10kt). The analysis of speed magnitude in the three spacing phases (Figure 29) shows that larger speed magnitudes are performed in the "remain" phase in which most of changes in target state occurred. The average speed magnitudes are similar in LFPO and LFPG scenarios.

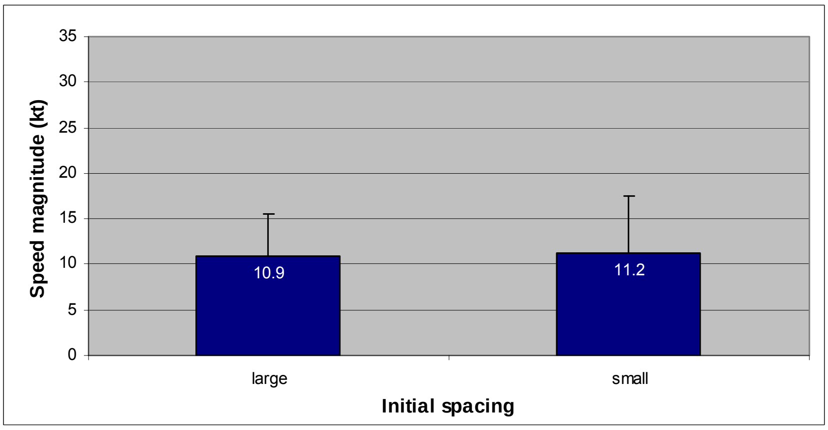

Figure 28: Average magnitude of speed actions.

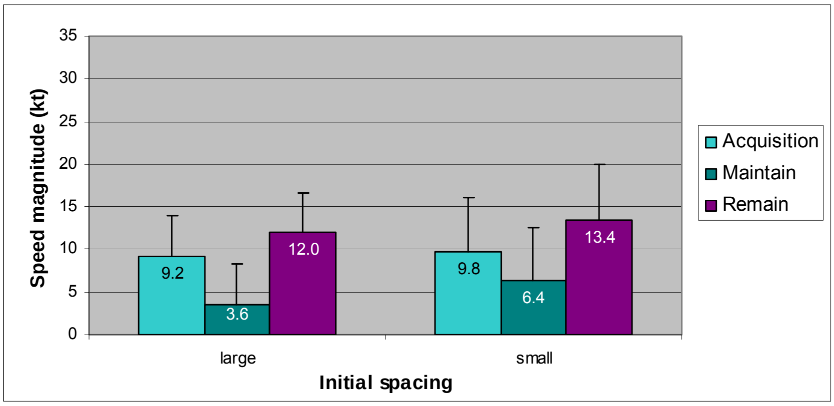

Figure 29: Average magnitude of speed actions per spacing phase.

To go a step further, the distribution of speed magnitude was analysed. Globally, the initial spacing deviation had no impact on the shape of the distribution. In the approach phase, 68% of the speed actions were adjustments comprised between -15kt and +5kt. However, large speed changes occur in runs with large initial spacing deviation and in runs with small initial spacing deviation (Figure 30 and Figure 31). The cases of large speed magnitude are described in 6.5.3. The same shape is observed in LFPO and LFPG scenarios (see annex 8). Then, the same analysis was conducted for each spacing phase (Figure 32 to Figure 34). The results show the same shape in each phase. Very few actions were performed in the "maintain" phase of the condition with large initial spacing deviation, as the duration of this phase is rather small. These are positive results as a series of large accelerations and decelerations could be detrimental to flight efficiency and may induce oscillations for the following aircraft. However, too numerous speed actions could induce too much focus on speed and thus resulting in excessive monitoring.

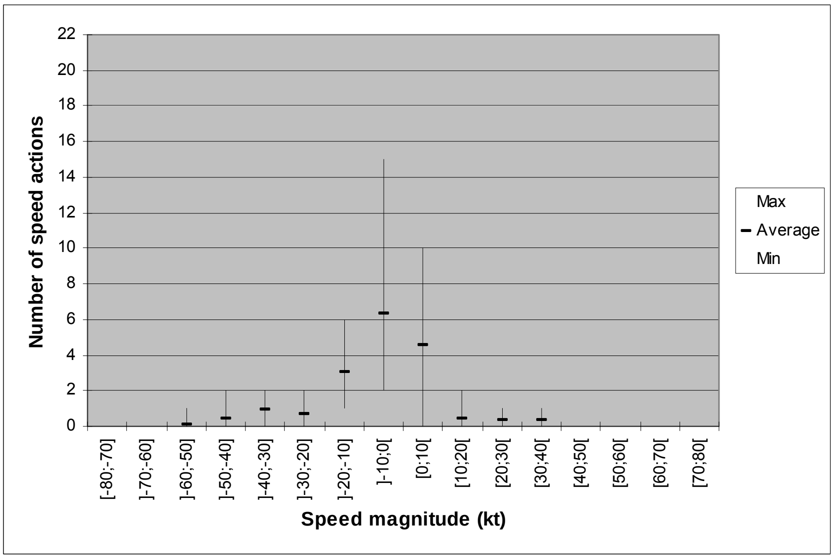

Figure 30: Distribution of speed actions magnitude in the large initial spacing deviation condition.

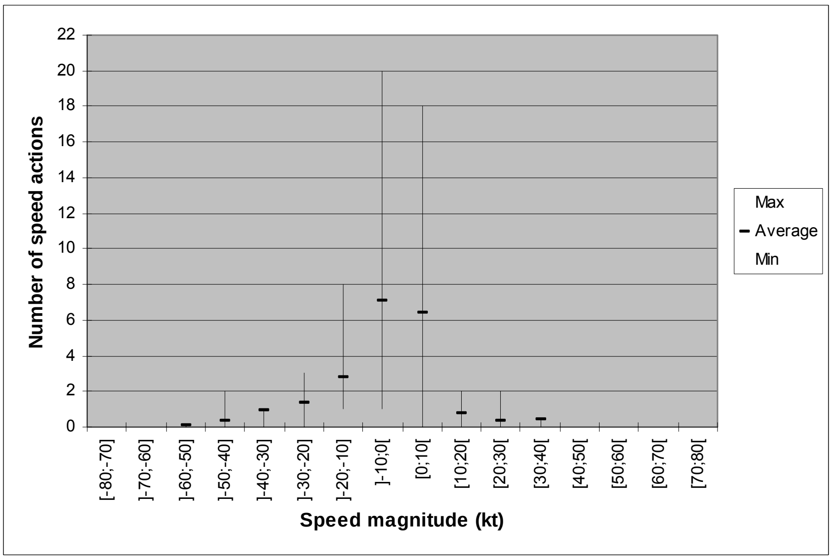

Figure 31: Distribution of speed actions magnitude in the small initial spacing deviation condition.

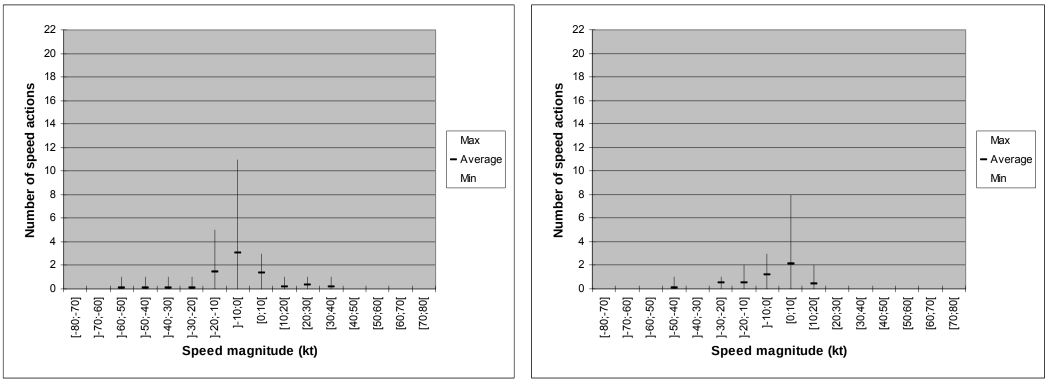

Figure 32: Distribution of speed actions magnitude in the "acquisition" phase of the large (left) and small (right) initial spacing deviation condition.

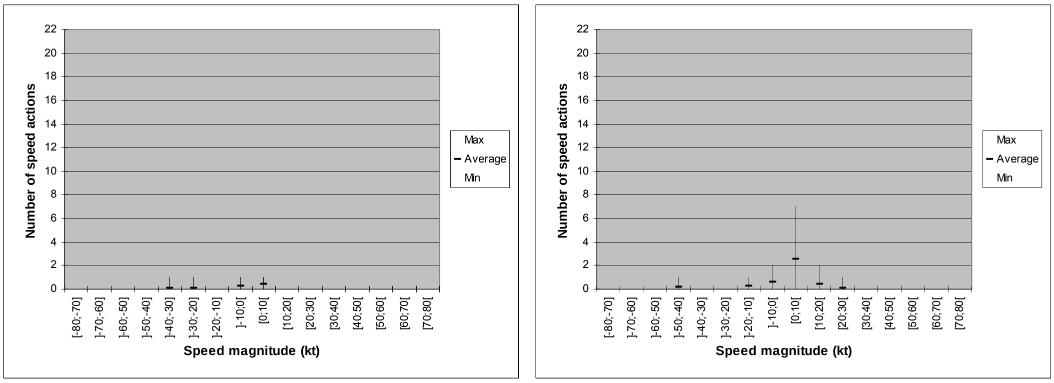

Figure 33: Distribution of speed actions magnitude in the "maintain" phase of the large (left) and small (right) initial spacing deviation condition.

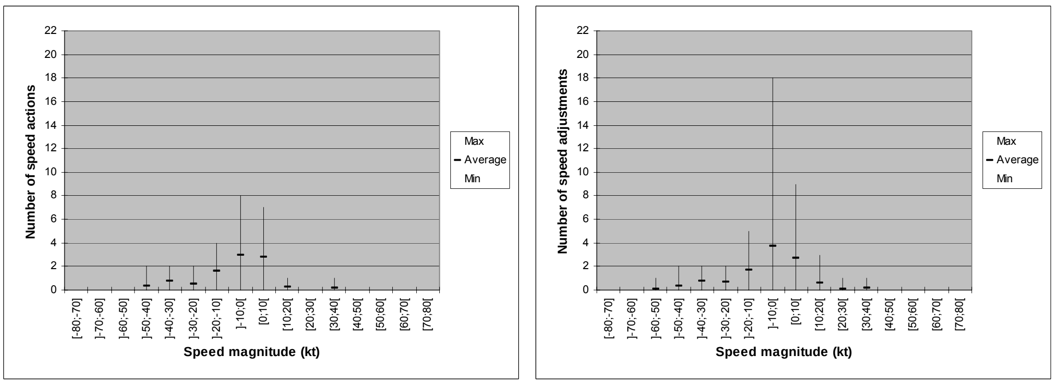

Figure 34: Distribution of speed actions magnitude in the "remain" phase of the large (left) and small (right) initial spacing deviation condition.

To get a better understanding of the speed actions, the relation between the number of speed actions and speed magnitude was analysed. As expected but unlike the previous experiment, the results (Figure 35) show that larger speed variations induced less frequent speed actions.

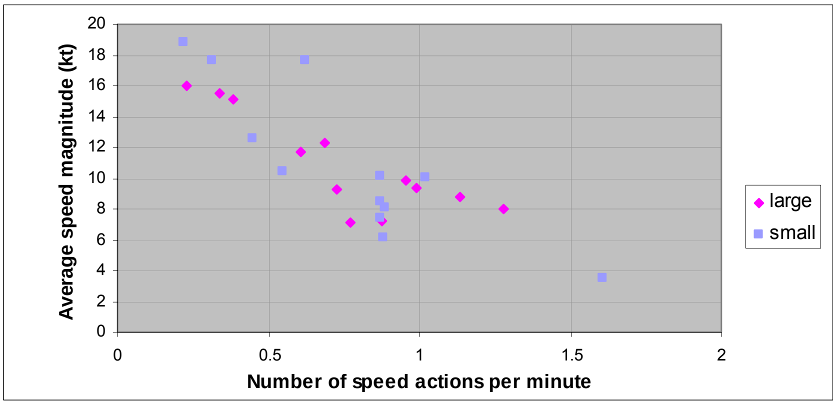

Figure 35: Relationship between average speed actions magnitude and number of speed actions per minute.

6.4.8. Synthesis on Activity

The impact of time-based spacing on flight crews' activity was assessed through the analysis of the speed actions. Speed actions performed at the beginning aimed at acquiring the required spacing then speed actions were mostly triggered by changes in target state (descents and speed reductions). The average number of speed actions was less than 1 per minute, and most speed actions were adjustments comprised between -15kt and +5kt.

6.5. EFFECTIVENESS

6.5.1. Subjective Feedback

Each crew felt they successfully achieved the spacing task and that the spacing was maintained within the fixed spacing tolerance. The spacing task might impact positively on fuel consumption since it should reduce holding patterns.

6.5.2. Spacing Accuracy

Effectiveness of the spacing task was assessed though the spacing accuracy. During the "acquisition" phase; the spacing deviation might be outside the spacing tolerance. Therefore, the spacing deviation was analysed during the "maintain" and the "remain" phase. As a reminder, the "acquisition" phase ended when the spacing deviation had to be below 3 seconds and the closure rate near 0 (±2kt).

The results (Figure 36) show that the average spacing deviation was 1 second or even less which is far below the spacing tolerance (5 seconds). The tolerance margin was not fully used by pilots. For most of them, the strategy was to look for the exact required value ("keep the bug aligned" culture) even though it leads to an increase in the number of speed actions, as identified in the December'02 flight deck experiment. The average spacing deviation was similar in LFPO and LFPG scenarios (see annex 9).

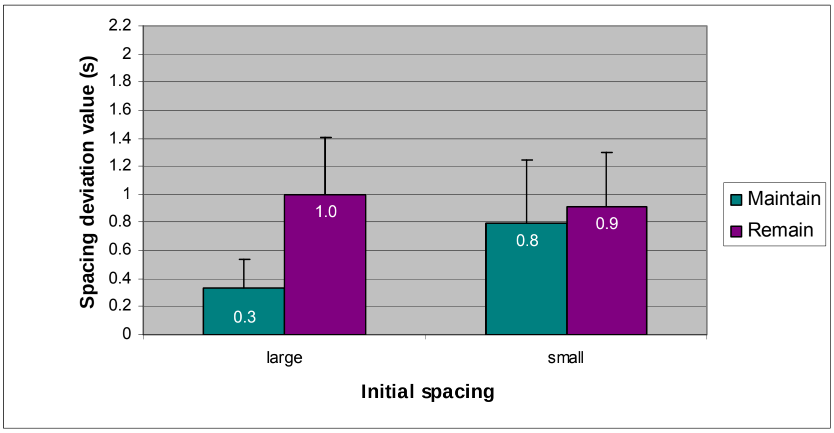

Figure 36: Average spacing deviation.

To extend the analysis, the distribution of average spacing deviation was analysed. Figure 37 shows the average spacing deviation for each condition. In both "maintain" and "remain" phases, the average value is always below 2.5 seconds. Figure 38 shows the maximum spacing deviation for each condition. In both "maintain" and "remain" phases, the max value is always below the spacing tolerance. Largest spacing deviations were observed in the "remain" phase, possibly reflecting the time needed to react to changes in target state (starts of descent and speed reductions) and/or the fact that the equivalent spacing tolerance expressed in distance is lower at lower speeds and altitude[6]. The same shape is observed in LFPG and LFPO scenarios (see annex 9).

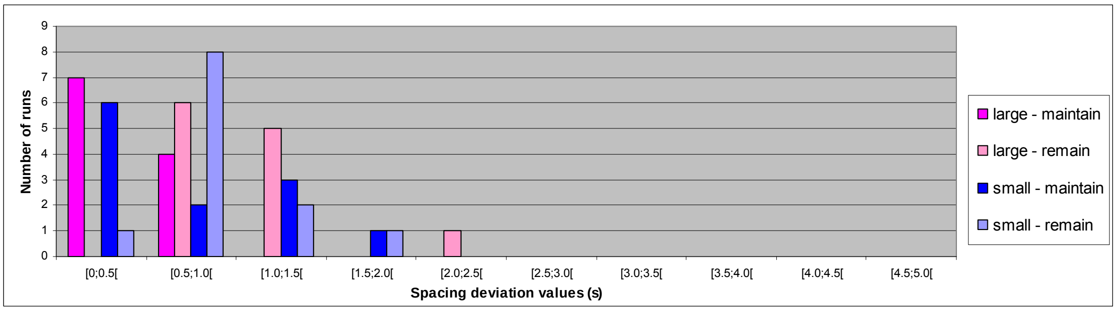

Figure 37: Distribution of average spacing deviation values.

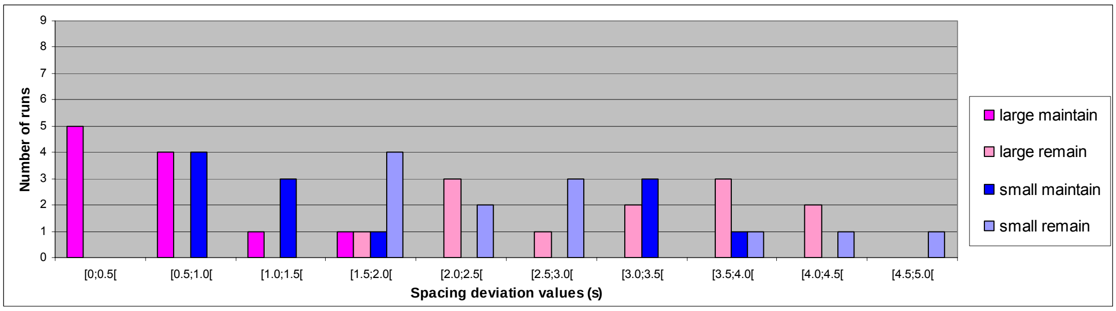

Figure 38: Distribution of maximum spacing deviation values.

6 It should be noted that for a constant spacing tolerance in time the equivalent distance-based spacing decreases as speed and altitude decrease. For the ±5s time-based spacing tolerance used during the simulation, the equivalent distance-based spacing tolerance was around ±0.6NM in cruise, around ±0.5NM at FL110 and around ±0.35NM below FL100. This means that a change in target state might have a greater impact on the spacing deviation at low altitudes than in cruise.

6.5.3. Large Speed Magnitude

The magnitude of the speed actions needed to perform the spacing task may have an impact on fuel consumption, engine life and stability of chains of aircraft under spacing. Most pilots performed speed adjustments of small magnitude (cf. 6.4.7). Cases of speed actions with magnitude greater than 30 knots were analysed. The objective was to understand what caused such large adjustments. 26 cases were observed in 16 out of 24 runs, corresponding to 6 crews (all crews).

20 cases corresponded to adjustment to target speed reduction (12 to target speed reduction to 250kt and 8 to target speed reduction to 220kt). Performing only one action instead of many is likely to generate a speed profile closer to the optimal, which is beneficial for fuel consumption and engine life. Moreover, it has an impact on pilot's activity as less speed actions are performed.

2 cases corresponded to a too early anticipation of the target speed reduction followed by an acceleration in correction to this anticipation. Those induced accelerations have a very negative impact on fuel consumption and engine life. They might induce as well instability in chains of spacing instructed aircraft. Moreover, it has an impact on pilot's activity as more speed actions are performed.

2 cases corresponded to the initial speed adjustment required to follow the suggested airspeed. The initial speed adjustment was larger than for other crews due to a late flight crew action.

6.5.4. Synthesis on Effectiveness

Every crew successfully achieved the spacing task: the spacing deviation was maintained within the tolerance margins (5 seconds). Most pilots looked for the exact required value (average spacing deviation of 1 second) even though it could lead to an increase in the number of speed actions. This was probably due to the "keep the bug aligned" culture. Largest spacing deviations were possibly due to the time needed to react to changes in target state. Effectiveness (fuel consumption, engine life, stability of chains of aircraft) could be impacted by some speed actions of large magnitude.

6.6. SAFETY

6.6.1. Subjective Feedback

For most pilots, the spacing task enhanced safety as they got a better understanding of the context, and were more involved in the management of their situation with respect to the preceding aircraft. However they noticed a slight focalisation on the ND that might lead to reduce the monitoring of flight parameters (and TCAS traffic). This feedback would require further investigation, in particular with an eye-tracking device. Moreover, they mentioned that every speed change on the FCU was a potential source of error. In an operational context, the managed spacing mode would be required. For most pilots, frequency and severity of errors would be the same with and without the spacing task.

6.6.2. Missed Communications

The radio party-line included ATC instructions for the cockpit simulator. Some cases were experienced when pilots missed their instructions, which were then reissued by the pseudo-controller. As communication with ATC and communication in the cockpit were not measured, the causes and the consequences of the missed instructions could not be analysed.

6.6.3. Loss of Spacing

The spacing was considered as lost when spacing deviation was outside the spacing tolerance. No case of loss of spacing was observed in this experiment.

6.6.4. Synthesis on Safety

A possible gain in safety was mentioned, due to a better understanding of the context and a better involvement in the management of their situation with respect to the preceding aircraft. Pilots noticed a slight focalisation on the spacing scale that might lead to reduce monitoring of flight parameters. Moreover, they mentioned that every speed action was a potential source of error. In an operational context a managed spacing mode would be required. No case of loss of spacing was observed.

7. CONCLUSION

The purpose of this document was to present the results and findings of the CoSpace flight deck experiment conducted in June 2003. The objective of this experiment was to assess the use of spacing in time down to final approach. A recurrent secondary objective was to assess the evolutions of cockpit interface.

To analyse time-based spacing, four dimensions were considered: human shaping factors, flight crew activity, effectiveness and safety. To compare distance-based to time-based, the focus was put on human shaping factors (limited amount of data in distance-based). Compared to the 2002 experiment, although objectives were different, consistent feedback was received and similar trends were observed (e.g. characteristics of speed actions, spacing deviation). Considering the 2003 objectives, the spacing task was feasible down to final approach, and time-based spacing was preferred to distance-based. Findings on each dimension are summarised below.

7.1. HUMAN SHAPING FACTORS

The overall feedback was positive. The spacing task was motivating and perceived as quite compatible with usual flying tasks despite an increase of mental effort which remained acceptable in the part-task simulation environment. Perceived benefits were: better understanding of the situation and anticipation, lower communication load due to less frequent exchanges with controllers. Time-based spacing was felt easier to handle. Even though information displays were appreciated, some pilots asked for a managed spacing mode.

7.2. FLIGHT CREW ACTIVITY

The impact of time-based spacing on flight crews' activity was assessed through the analysis of the speed actions. Speed actions performed at the beginning aimed at acquiring the required spacing then speed actions were mostly triggered by changes in target state (descents and speed reductions). The average number of speed actions was less than 1 per minute, and most speed actions were adjustments comprised between -15kt and +5kt.

7.3. EFFECTIVENESS

Every crew successfully achieved the spacing task: the spacing deviation was maintained within the tolerance margins (5 seconds). Most pilots looked for the exact required value (average spacing deviation of 1 second) even though it could lead to an increase in the number of speed actions. This was probably due to the "keep the bug aligned" culture. Largest spacing deviations were possibly due to the time needed to react to changes in target state. Effectiveness (fuel consumption, engine life, stability of chains of aircraft) could be impacted by some speed actions of large magnitude.

7.4. SAFETY

A possible gain in safety was mentioned, due to a better understanding of the context and a better involvement in the management of their situation with respect to the preceding aircraft. Pilots noticed a slight focalisation on the spacing scale that might lead to reduce monitoring of flight parameters. Moreover, they mentioned that every speed action was a potential source of error. In an operational context a managed spacing mode would be required. No case of loss of spacing was observed.

7.5. NEXT STEPS

Next steps will consist in assessing the effect of various reactions of preceding aircraft under airborne spacing. Improvements of the interface will be considered, mainly on the suggested airspeed (filtering, anticipation). Experiments on a full-flight simulator are envisaged to assess feasibility in a more realistic environment and the impact on pilot monitoring (use of an eye-tracker).

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TRADUCTION EN LANGUE FRANÇAISE

RÉSUMÉ

Ce rapport présente les résultats de l'expérimentation bord conduite en juin 2003 dans le cadre du projet CoSpace. Cette expérimentation s'insère dans une série d'exercices de validation, sol et bord, visant à étudier l'utilisation d'instructions d'espacement pour le séquencement des flux d'arrivées. Les expérimentations bord précédentes conduites en mai et décembre 2002 visaient à évaluer la tâche d'espacement en distance de la phase de croisière à l'approche initiale. L'expérimentation sol précédente, conduite en novembre 2002 introduisait les instructions d'espacement en temps et ce jusqu'à l'approche finale. La présente expérimentation reposait sur ces expérimentations. Son objectif était d'évaluer la tâche d'espacement en temps jusqu'à l'approche finale du pont de vue des pilotes. L'évaluation des évolutions de l'interface homme-machine était un objectif secondaire récurrent.

Six équipages de deux pilotes de ligne ont participé à cette expérimentation. Les scénarios consistaient en des arrivées, de la phase de croisière à l'approche finale, et duraient environ 40 minutes. Ils étaient insérés dans des rejeux d'exercices contrôleur avec les instructions ATC et le trafic environnant. Les équipages avaient pour consigne de réaliser la tâche d'espacement en vitesse « sélectée » avec le support d'indications graphiques, en plus de leurs tâches de vol habituelles (communication avec l'ATC, mise à jour du plan de vol exploitation, préparation de l'arrivée et briefing). L'expérimentation a été réalisée sur un simulateur de cockpit.

Pour analyser la tâche d'espacement en temps, quatre dimensions étaient considérées : facteurs humains, activité de l'équipage, efficacité et sécurité. Pour comparer la tâche d'espacement en temps et en distance, l'accent a été mis sur les facteurs humains. En comparaison de l'expérimentation menée en 2002, bien que les objectifs fussent différents, les retours des pilotes étaient cohérents et les tendances similaires. Concernant les objectifs 2003, la tâche d'espacement s'est avérée faisable jusqu'à l'approche finale et l'espacement en temps était préféré à l'espacement en distance.

Le retour général des pilotes était positif. La tâche d'espacement était motivante et perçue comme plutôt compatible avec les tâches de vol habituelles malgré l'augmentation de la charge de travail qui reste acceptable dans l'environnement de simulation. Les bénéfices perçus étaient : meilleure compréhension de la situation, meilleure anticipation et charge de communication plus faible grâce à des échanges moins fréquents avec les contrôleurs. Les pilotes ont perçu la tâche d'espacement en temps plus facile à gérer. Même si les interfaces homme-machine étaient appréciées, certains pilotes ont demandé un mode « managé ».

L'activité des pilotes lors de la tâche d'espacement a été analysée à travers les actions de vitesse. Les actions réalisées en début visaient à acquérir l'espacement. Les suivantes étaient pour la plupart dues aux changements d'état de la cible (descentes et réductions de vitesse). Le nombre moyen d'actions de vitesse était inférieur à 1.5 par minute et la plupart d'entre elles consistaient en des ajustements compris entre -15kt et +5kt.

Tous les équipages ont réussi la tâche d'espacement : l'écart à l'espacement restait dans les marges de tolérance (5 secondes). La plupart des pilotes recherchait la valeur d'espacement exacte (écart d'espacement moyen d'1 seconde) même si cela pouvait augmenter le nombre d'actions de vitesse. Ceci était probablement causé par la culture « aligner les barres ». Les écarts les plus importants devraient être dus au temps nécessaire pour réagir aux changements d'état de la cible. Certaines actions de vitesse de grande amplitude pourraient avoir des conséquences sur l'efficacité (consommation de carburant, durée de vie du moteur, stabilité des chaînes d'avions).

Il a été mentionné un gain éventuel en sécurité, grâce à une meilleure compréhension du contexte et une implication plus grande dans la gestion de la situation par rapport à l'avion précédent. Les pilotes ont noté une légère focalisation sur l'échelle d'espacement qui pourrait réduire la surveillance (« monitoring ») des paramètres de vol. De plus, ils mentionnaient que chaque action de vitesse était une source d'erreur potentielle. Dans un contexte opérationnel, le mode « managé » serait requis.

Les étapes suivantes consisteront en l'évaluation de l'effet de différentes réactions de l'avion précédent sous espacement. Les améliorations de l'interface homme-machine, principalement la vitesse suggérée, seront apportées. Des expérimentations dans un simulateur de vol sont envisagées pour évaluer la faisabilité dans un environnement plus réaliste et l'impact sur la surveillance.

1. INTRODUCTION

Le but de ce document est de présenter les résultats de l'expérimentation bord conduite en juin 2003 dans le cadre du projet CoSpace. Cette expérimentation s'insère dans une série d'exercices de validation, sol et bord, visant à étudier l'utilisation d'instructions d'espacement pour le séquencement des flux d'arrivées. Les expérimentations bord précédentes conduites en mai et décembre 2002 visaient à évaluer la tâche d'espacement en distance de la phase de croisière à l'approche initiale. L'expérimentation sol précédente, conduite en novembre 2002 introduisait les instructions d'espacement en temps et ce jusqu'à l'approche finale. La présente expérimentation reposait sur ces expérimentations. Son objectif était d'évaluer la tâche d'espacement en temps jusqu'à l'approche finale du point de vue des pilotes. L'évaluation des évolutions de l'interface homme-machine était un objectif secondaire récurrent.

Le présent document est organisé comme suit :

- La section 2 présente les instructions d'espacement.
- La section 3 présente le contexte et les objectifs de l'expérimentation.
- La section 4 décrit la conception de l'expérimentation.
- La section 5 décrit les données collectées et leur analyse.
- La section 6 présente les résultats.
- La section 7 présente les conclusions.

2. OBJECTIFS

Les objectifs de l'expérimentation étaient d'évaluer :

- La faisabilité de la tâche d'espacement dans la phase d'**approche** lorsque la charge de travail augmente de par la préparation de l'atterrissage.
- L'impact de la tâche d'**espacement en temps** sur l'activité de l'équipage et l'efficacité dans les phases de descente et d'approche en faisant varier l'espacement initial.
- L'évolution de l'**interface homme-machine**.

3. CONCLUSIONS

Le but de ce document est de présenter les résultats de l'expérimentation bord conduite en juin 2003 dans le cadre du projet CoSpace. L'objectif de cette expérimentation était d'évaluer la tâche d'espacement en temps jusqu'à l'approche finale. L'évaluation des évolutions de l'interface homme-machine était un objectif secondaire récurrent.

Pour analyser la tâche d'espacement en temps, quatre dimensions étaient considérées : facteurs humains, activité de l'équipage, efficacité et sécurité. Pour comparer la tâche d'espacement en temps et en distance, l'accent a été mis sur les facteurs humains (quantité de données limitée en distance). En comparaison de l'expérimentation menée en 2002, bien que les objectifs fussent différents, les retours des pilotes étaient cohérents et les tendances similaires (par exemple, caractéristiques des actions de vitesse, écart à l'espacement requis). Concernant les objectifs 2003, la tâche d'espacement s'est avérée faisable jusqu'à l'approche finale et l'espacement en temps était préféré à l'espacement en distance. Les résultats sont résumés ci-dessous pour chaque dimension.

3.1. FACTEURS HUMAINS

Le retour général des pilotes était positif. La tâche d'espacement était motivante et perçue comme plutôt compatible avec les tâches de vol habituelles malgré l'augmentation de la charge de travail qui reste acceptable dans l'environnement de simulation. Les bénéfices perçus étaient : meilleure compréhension de la situation, meilleure anticipation et charge de communication plus faible grâce à des échanges moins fréquents avec les contrôleurs. Les pilotes ont perçu la tâche d'espacement en temps plus facile à gérer. Même si l'interface homme-machine était appréciée, certains pilotes ont demandé un mode « managé ».

3.2. ACTIVITE DES PILOTES

L'activité des pilotes lors de la tâche d'espacement a été analysée à travers les actions de vitesse. Les actions réalisées en début visaient à acquérir l'espacement. Les suivantes étaient pour la plupart dues aux changements d'état de la cible (descentes et réductions de vitesse). Le nombre moyen d'actions de vitesse était inférieur à 1.5 par minute et la plupart d'entre elles consistaient en des ajustements compris entre -15kt et +5kt.

3.3. EFFICACITE

Tous les équipages ont réussi la tâche d'espacement : l'écart à l'espacement restait dans les marges de tolérance (5 secondes). La plupart des pilotes recherchait la valeur d'espacement exacte (écart d'espacement moyen d'1 seconde) même si cela pouvait augmenter le nombre d'actions de vitesse. Ceci était probablement causé par la culture « aligner les barres ». Les écarts les plus importants devraient être dus au temps nécessaire pour réagir aux changements d'état de la cible. Certaines actions de vitesse de grande amplitude pourraient avoir des conséquences sur l'efficacité (consommation de carburant, durée de vie du moteur, stabilité des chaînes d'avions).

3.4. SECURITE

Il a été mentionné un gain éventuel en sécurité, grâce à une meilleure compréhension du contexte et une implication plus grande dans la gestion de la situation par rapport à l'avion précédent. Les pilotes ont noté une légère focalisation sur l'échelle d'espacement qui pourrait réduire la surveillance (« monitoring ») des paramètres de vol. De plus, ils mentionnaient que chaque action de vitesse était une source d'erreur potentielle. Dans un contexte opérationnel, le mode « managé » serait requis. Aucun cas de perte d'espacement n'a été observé.

3.5. EXPERIMENTATIONS FUTURES

Les étapes suivantes consisteront en l'évaluation de l'effet de différentes réactions de l'avion précédent sous espacement. Les améliorations de l'interface homme-machine, principalement la vitesse suggérée (filtre et anticipation), seront aussi considérées. Des expérimentations dans un simulateur de vol sont envisagées pour évaluer la faisabilité dans un environnement plus réaliste et l'impact sur la surveillance (utilisation d'un dispositif de suivi du regard, « eye-tracker »).