COSPACE 2002 FLIGHT DECK EXPERIMENTS
ASSESSING THE IMPACT OF SPACING INSTRUCTIONS FROM CRUISE TO INITIAL APPROACH

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This report presents the results and findings of the CoSpace flight deck experiments conducted in May and December 2002. These experiments formed part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions (denoted airborne spacing) for sequencing of arrival flows. The previous flight deck experiment conducted in November 2000 aimed at assessing feasibility of spacing tasks, mainly through interface usability. The present experiments aimed at going a step further by assessing feasibility and impact on flight crew activity and on effectiveness. This was investigated from cruise to initial approach, using distance-based spacing, with a target aircraft under conventional control. In May, three spacing instructions were considered, whereas, in December, only one was considered to allow varying three spacing tolerances. Five and seven crews took part in the experiment, one day each, in May and in December respectively. The flight crews were tasked to perform the spacing task through manual speed adjustments in addition to their conventional flight tasks on a part-task cockpit simulator. Flight crews perceived benefits introduced by the spacing task (taking an active part in the management of the spacing, better understanding of the situation). However, they dread either to focus too much on the spacing task during busy flight phases or to forget it when no action is needed during a long period of time. Pilots managed to maintain the spacing within tolerances, and despite a higher perceived workload for the pilot flying, it is described as acceptable by flying and non-flying pilots. A managed mode was requested by some pilots. The analysis of pilot activity focused on the manual speed actions required to perform the spacing task, and the eye tracker data analysis allows identifying metrics to assess the impact of the spacing task on pilots monitoring.
EXECUTIVE SUMMARY

This report presents the results and findings of the CoSpace flight deck experiments conducted in May and December 2002. These experiments formed part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions (denoted airborne spacing) for sequencing of arrival flows. The previous flight deck experiment conducted in November 2000 aimed at assessing feasibility of spacing tasks, mainly through interface usability. The present experiments aimed at going a step further by assessing feasibility and impact on flight crew activity and on effectiveness. This was investigated from cruise to initial approach, using distance-based spacing, with a target aircraft under conventional control. In May, three spacing instructions were considered, whereas, in December, only one was considered to allow varying three spacing tolerances.

May'02 experiment

The objectives of this experiment were to investigate the feasibility of three spacing instructions ("remain", “merge” and “heading then merge”) and their impact on flight crew activity and effectiveness.

Five crews (two test pilots and eight airlines pilots) took part in the experiment, one day each. The flights were Paris Orly arrivals. The flight crew was tasked to perform the spacing task through manual speed adjustments in addition to their conventional flight tasks on a part-task cockpit simulator.

Flight crews perceived benefits introduced by the spacing task, typically the active part they take in the management of the spacing and the better understanding of the situation. Additional support to perform the spacing task, through improved interface is requested (speed advisory for manual mode or a managed mode). Despite a higher mental and temporal perceived workload for the pilot flying, the workload is described as acceptable by flying and non flying pilots.

The analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is below 1.5 per minute. No difference in terms of speed actions was found across experimental conditions (type of spacing instruction and initial flight phase of the target). In terms of magnitude, 65% of speed actions correspond to rather small adjustments (between -15kt and +5kt). Despite the basic assistance and the manual mode, pilots could in all conditions maintain the required spacing within tolerance margin (+/-1NM).

December'02 experiment

The objectives of this experiment were to assess the relation between three spacing tolerances (+/-1NM, +/-0.5NM and +/-0.25NM) and flight crew activity, effectiveness as well as safety with the "merge" instruction.

Seven crews (two test pilots and twelve airlines pilots) took part in the experiment, one day each. The flights were Paris Orly and Paris Charles-De-Gaulle arrivals. As in May’02, the flight crew was tasked to perform the spacing task through manual speed adjustments in addition to their conventional flight tasks on a part-task cockpit simulator. The simulation realism was improved by “inserting” each flight in a scenario previously recorded with an air traffic controller.

As in May’02, pilot feedback was positive. The increased workload with the spacing instruction is considered as acceptable.
However the smallest tolerance margin (+/-0.25NM) induced higher perceived workload, especially for the pilot flying and was perceived as more demanding in terms of monitoring. Modification on the interface improved its usability, but the managed mode was still a request from some pilots.

As in May’02, the analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is less than 1.5 per minute with fewer speed actions for larger tolerances (respectively 1.7, 1.3 and 1 per minute). However, the impact of tolerance is less important than expected, which may be explained by the “keep the bug aligned” culture. The frequency of the speed actions could be split into two categories: less than 3 minutes (actions mainly linked to changes on target state) and between 6 and 7 minutes. In terms of magnitude, 65% of speed actions correspond to small speed adjustments (between -15kt and +5kt). The analysis of speed actions confirms results from May’02. In addition, it shows the impact of spacing tolerance on speed actions – smaller tolerance being more demanding.

The eye tracker data analysis allows identifying metrics to assess the impact of the spacing task on pilots monitoring. Similarly to the ground experiments, three sets of metrics have been identified: macroscopic for the impact on the overall fixation distribution, microscopic for the impact on the monitoring of areas of interest, and qualitative for pilot scanning patterns in assessing transition between areas of interest.

Pilots managed to maintain the spacing within tolerance margins except few cases discussed in the report. The average spacing deviation was usually below 0.15NM. The maximum spacing deviation was usually below the margin tolerance.

Concerning safety, pilot feedback was rather positive. Compared to today situations, the situation awareness is better for the majority of pilots: crews feel safer, get a better understanding of the situation and feel more involved. However they dread either to focus too much on the spacing task during busy flight phases or to forget it when no action is needed during a long period of time.

Conclusion

These experiments enabled to get an overall understanding of the impact of airborne spacing on pilot activity and on flight effectiveness in cruise and in descent. The new spacing task was performed successfully and fitted into the current flying activity.

The main objective of the next air experiment in mid 2003 will be to assess the feasibility of time-based airborne spacing until the final approach phase. The assessment will rely on the same methodology but the validation model will be updated so as to match the last version designed for ground experiments.
ACKNOWLEDGEMENTS

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<th>De-Code</th>
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<tr>
<td>ACAS</td>
<td>Airborne Collision Avoidance System</td>
</tr>
<tr>
<td>ACC</td>
<td>Area Control Center</td>
</tr>
<tr>
<td>ADF</td>
<td>Automatic Direction Finder</td>
</tr>
<tr>
<td>ADS-B</td>
<td>Automatic Dependant Surveillance – Broadcast</td>
</tr>
<tr>
<td>ASAS</td>
<td>Airborne Separation Assistance System</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>ATIS</td>
<td>Automatic Terminal Information Service</td>
</tr>
<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
</tr>
<tr>
<td>CDTI</td>
<td>Cockpit Display of Traffic Information</td>
</tr>
<tr>
<td>DES</td>
<td>Managed Descent Mode</td>
</tr>
<tr>
<td>DIR TO</td>
<td>Direct To</td>
</tr>
<tr>
<td>DIS</td>
<td>Distributed Interactive Simulation</td>
</tr>
<tr>
<td>EACAC</td>
<td>Evolutionary Air-ground Co-operative ATM Concept</td>
</tr>
<tr>
<td>EATCHIP</td>
<td>European ATC Harmonisation and Integration Programme</td>
</tr>
<tr>
<td>ECAM</td>
<td>Electronic Centralised Aircraft Monitor</td>
</tr>
<tr>
<td>ED</td>
<td>Engine Display</td>
</tr>
<tr>
<td>EEC</td>
<td>EUROCONTROL Experimental Centre</td>
</tr>
<tr>
<td>EFIS CP</td>
<td>Electronic Flight Instrument System Control Panel</td>
</tr>
<tr>
<td>E-TMA</td>
<td>Extended Terminal Manoeuvring Area</td>
</tr>
<tr>
<td>FCU</td>
<td>Flight Control Unit</td>
</tr>
<tr>
<td>FL</td>
<td>Flight Level</td>
</tr>
<tr>
<td>GS</td>
<td>Ground Speed</td>
</tr>
<tr>
<td>HMI</td>
<td>Human Machine Interface</td>
</tr>
<tr>
<td>IAF</td>
<td>Initial Approach Fix</td>
</tr>
<tr>
<td>IAS</td>
<td>Indicated Air Speed</td>
</tr>
<tr>
<td>LFPG</td>
<td>Paris Charles-De-Gaulle Airport (ICAO code)</td>
</tr>
<tr>
<td>LFPO</td>
<td>Paris Orly Airport (ICAO code)</td>
</tr>
<tr>
<td>LSK</td>
<td>Line Select Key</td>
</tr>
<tr>
<td>MCDU</td>
<td>Multi purpose Control Display Unit</td>
</tr>
<tr>
<td>N/A</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>NASA-TLX</td>
<td>NASA Task Load Index</td>
</tr>
<tr>
<td>ND</td>
<td>Navigation Display</td>
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<tr>
<td>NM</td>
<td>Nautical Mile</td>
</tr>
<tr>
<td>OP DES</td>
<td>Open Descent Mode</td>
</tr>
<tr>
<td>PF</td>
<td>Pilot Flying</td>
</tr>
<tr>
<td>PFD</td>
<td>Primary Flight Display</td>
</tr>
<tr>
<td>PNF</td>
<td>Pilot Not Flying</td>
</tr>
<tr>
<td>R/T</td>
<td>Radio/Telecommunication</td>
</tr>
<tr>
<td>SSR code</td>
<td>Secondary Surveillance Radar code</td>
</tr>
<tr>
<td>TCAS</td>
<td>Traffic Collision Alert System</td>
</tr>
<tr>
<td>TIS-B</td>
<td>Traffic Information Service – Broadcast</td>
</tr>
<tr>
<td>TMA</td>
<td>Terminal Manoeuvring Area</td>
</tr>
<tr>
<td>VOR</td>
<td>VHF Omnidirectional Range</td>
</tr>
<tr>
<td>WPT</td>
<td>Waypoint</td>
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1. INTRODUCTION

The purpose of this document is to present the results and findings of the CoSpace flight deck experiments conducted in May and December 2002. These experiments formed part of a series of air and ground validation exercises aiming at investigating the use of spacing instructions (denoted airborne spacing) for sequencing arrival flows. The previous flight deck experiment conducted in November 2000 aimed at assessing feasibility of spacing tasks, mainly through interface usability. The present experiments aimed at going a step further by assessing feasibility and impact on flight crew activity and on effectiveness. This was investigated from cruise to initial approach, using distance-based spacing. In May, three spacing instructions were considered, whereas, in December, only one was considered to allow varying three spacing tolerances. The controller experiment conducted in November 2002 is reported in a separate document (CoSpace 2003).

The present document is organised as follows:

- Section 2 introduces the principles of spacing instruction.
- Section 3 introduces the experiment objectives and the method of analysis.
- Section 4 describes the experiment conducted in May 2002.
- Section 5 describes the experiment conducted in December 2002.
- Section 6 summarises the main findings and defines the next steps.

2. PRINCIPLES

2.1. MOTIVATION

New allocation of spacing tasks between controller and flight crew is envisaged as one possible option to improve air traffic management. 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. This allocation of spacing tasks to flight crew – denoted airborne spacing1 – is expected to increase controller availability and to improve safety, which in turn could enable better efficiency and/or, 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 his situation. Airborne spacing assumes new surveillance capabilities (e.g. ADS-B) along with new airborne functions (ASAS).

2.2. STATE OF THE ART

Airborne spacing for arrival flows of aircraft was initially studied from a theoretical perspective through mathematical simulations, to understand the intrinsic dynamics of in-trail following aircraft and identify in particular possible oscillatory effects (Kelly & Abbott, 1984; Sorensen & Goka, 1983). Pilot perspective was also addressed through human-in-the-loop simulations (Pritchett & Yankovsky, 1998; Pritchett & Yankovsky, 2000; Williams, 1983) and flight trials (Oseguera-Lohr et al., 2002) essentially to assess feasibility. The ATC system perspective was considered through model-based simulations, to assess impact on arrival rate of aircraft (Hammer, 2000). Initial investigations were also performed with controllers in approach (Lee et al., 2003).

1 We used to call it “limited delegation” or “delegation of spacing tasks”, but the term “delegation” appeared to be misleading as it is sometimes understood as transfer of responsibility for separation.
2.3. PRINCIPLES

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: Spacing instructions for sequencing](image)

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 spacing instruction, 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 the annex.
### Table 2: A typical exchange between controller (left) and pilot (right)

<table>
<thead>
<tr>
<th>Sequencing of converging aircraft:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>XYZ, select target 1234.</td>
<td>Selecting target 1234, XYZ.</td>
</tr>
</tbody>
</table>

| 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, 1000 ft below. |  |

| The controller can then issue the spacing instruction: |  |
| XYZ, behind target, merge to WPT to be 8 miles (90 seconds) behind. | Merging to WPT to be 8 miles (90 seconds) 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. |

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).](image)
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. This capability is usually denoted Airborne Separation Assistance System² (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.

2.4. PAST STUDIES

In the scope of assessing the acceptance from controllers and measuring the impact on their activity, four human-in-the-loop experiments were carried out (June 1999, June 2000, November 2000 and November 2001), essentially focusing on the sequencing of arrival flows in ACC (extended TMA, denoted E-TMA). A total of 23 controllers from different European countries participated over a total duration of 9 weeks. For the last simulation, the airspace comprised four en-route sectors from Paris ACC handling south-east arrivals to Orly and Charles-De-Gaulle airports (and two associated simplified initial approach sectors). The traffic simulated was derived from a real traffic. To allow for comparison, each exercise was played twice: with and without spacing instruction. It was observed (through the distribution of manoeuvring instructions and location of eye fixations) that the use of spacing instructions partly relieves the controller of the maintaining of sequences, and allows him to concentrate on the building of sequences. This (positive) impact on controller activity resulted in more stable and homogeneous spacing between aircraft at exit point. Although promising, these investigations were exclusively focused on the E-TMA. Regarding the approach, preliminary investigations were carried out through a small scale simulation (June 2002) involving four approach controllers (during 1.5 day each). The objective was to identify possible use of spacing instruction and limits. Although spacing instruction was perceived as potentially beneficial for some situations (e.g. downwind leg), key issues remain such as the final integration of flows already delegated (EACAC 2001a).

Similarly, small scale pilot-in-the-loop experiments, involving a total of 10 airline pilots and 2 tests pilots were conducted in June 1999 and November 2000. The experiments essentially provided (interface) usability assessment. The flight crew overall feeling was positive and new requirements for spacing-related information display were identified (EACAC 2001b).

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² 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. FLIGHT DECK VALIDATION OBJECTIVES

3.1. CONTEXT AND OBJECTIVES

The previous experiment conducted in November 2000 aimed at assessing feasibility of spacing tasks, mainly through interface usability. It provided positive feedback and suggestions to improve the interface. The May'02 experiment aimed at going a step further. In addition to assessing the feasibility of three spacing instructions, the objective was to get a first insight into the impact on flight crew activity and effectiveness. Following pilot comments, the interface was improved (“spacing scale” and “suggested airspeed” added) and the simulation realism was increased (introduction of a simple TCAS display and party line) for the December'02 experiment. This experiment aimed at assessing the impact of three spacing tolerances on flight crew activity, effectiveness and safety.

Two sets of experimental conditions were derived from those objectives and summarised in Table 3.

<table>
<thead>
<tr>
<th>Flight phase</th>
<th>May’02</th>
<th>December’02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of spacing</td>
<td>Cruise to Initial Approach Fix</td>
<td>Cruise to Initial Approach Fix</td>
</tr>
<tr>
<td>Spacing instruction</td>
<td>Distance based</td>
<td>Without, distance based</td>
</tr>
<tr>
<td>Spacing tolerance</td>
<td>+/−1NM</td>
<td>+/- 0.25NM, +/-0.5NM, +/−1NM</td>
</tr>
<tr>
<td>Position in chain</td>
<td>Aircraft #2</td>
<td>Aircraft #2</td>
</tr>
<tr>
<td>Number of spacing instruction per flight</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Issue of spacing instruction</td>
<td>In cruise or in descent</td>
<td>In cruise</td>
</tr>
<tr>
<td>Destination</td>
<td>LFPO</td>
<td>LFPO, LFPG</td>
</tr>
<tr>
<td>Severity conditions</td>
<td>Nominal</td>
<td>Nominal</td>
</tr>
<tr>
<td></td>
<td>No wind</td>
<td>No wind</td>
</tr>
<tr>
<td>Spacing guidance cues</td>
<td>Spacing data block</td>
<td>Spacing scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suggested airspeed</td>
</tr>
<tr>
<td>Simulation environment</td>
<td>Cockpit: part task, no external view</td>
<td>Cockpit: part task, no external view</td>
</tr>
<tr>
<td></td>
<td>Traffic: target only</td>
<td>Traffic: all traffic in sector</td>
</tr>
<tr>
<td></td>
<td>ATC: instructions to flight crew only</td>
<td>ATC: instructions to flight crew and all traffic</td>
</tr>
</tbody>
</table>
3.2. VALIDATION MODEL

To guarantee a coherent view between air and ground experiments, four high level validation objectives were adapted from the controller experiments validation objectives defined in 2001 (EACAC 2001a): concept acceptability, impact on flight crew activity, on effectiveness and on safety (Table 4). The acceptability level referred to the relevance of the concept and the possible context for its application. It reflected how pilots perceive and use the system, and the required skills. The activity level investigated the integration of the concept within the overall flight activity. It assessed the compatibility with existing tasks, procedures and strategies. Beyond the issue of compatibility between tasks, it also includes a comparison between performed tasks in both conditions (conventional flight and flight with spacing instructions). The effectiveness level questioned the consequence of using spacing instructions on the quality of flying. In other words, it assessed the impact on the results of the flight deck activity, at a more systemic level (spacing accuracy, fuel consumption, respect of scheduled time, etc.). Last of all, the safety level aims at analysing if induced changes are acceptable in terms of safety, and assessing the risks induced and the mitigation means.

Table 4: High level objectives, metrics and measures related to flight deck analysis
Note that items in blue are investigated in the experiments presently reported.

<table>
<thead>
<tr>
<th>High level objectives</th>
<th>Metrics</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptability</td>
<td>Workload</td>
<td>Subjective feedback</td>
</tr>
<tr>
<td></td>
<td>Teamwork</td>
<td>Task distribution PF/PNF</td>
</tr>
<tr>
<td></td>
<td>Usefulness</td>
<td>Subjective feedback</td>
</tr>
<tr>
<td></td>
<td>Usability</td>
<td>Subjective feedback, number of errors, relative usage of displays</td>
</tr>
<tr>
<td>Flight crew activity</td>
<td>Communication task</td>
<td>Number and duration of messages</td>
</tr>
<tr>
<td></td>
<td>Aircraft flying task</td>
<td>Flying tasks (actions on flight parameters)</td>
</tr>
<tr>
<td></td>
<td>Spacing task</td>
<td>Number and magnitude of speed adjustments</td>
</tr>
<tr>
<td></td>
<td>Situation awareness task 1- collect information</td>
<td>Monitoring (fixations, scanning patterns, ...)</td>
</tr>
<tr>
<td></td>
<td>Situation awareness task 2 - interpret information</td>
<td>Subjective feedback, delay before reaction to target events</td>
</tr>
<tr>
<td></td>
<td>Prepare flight phases</td>
<td>Perform briefing, cross check</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Quality of Flying</td>
<td>Flight efficiency (fuel, speed profile, ...)</td>
</tr>
<tr>
<td></td>
<td>Respect of schedule time of arrival</td>
<td>Spacing accuracy</td>
</tr>
<tr>
<td></td>
<td>Pseudo controller perspective</td>
<td>Respect of instruction (reaction time, ...)</td>
</tr>
<tr>
<td>Safety</td>
<td>Error management</td>
<td>Predictive error model</td>
</tr>
<tr>
<td></td>
<td>Flight errors</td>
<td>Alarms, actions omissions</td>
</tr>
<tr>
<td></td>
<td>Spacing task-related errors</td>
<td>Loss of spacing, execution errors</td>
</tr>
</tbody>
</table>
4. MAY’02 EXPERIMENT

4.1. EXPERIMENT OBJECTIVES

The objectives of the present experiment were:

- To investigate the feasibility of three spacing instructions ("remain", "merge" and "heading then merge") including usability interface.
- To get a first insight into the impact on flight crew activity and effectiveness.

4.2. HYPOTHESES

Three sets of hypotheses were defined based on the experiment objectives, the principles of airborne spacing and flight crew activity:

The first set of hypotheses deals with the spacing instructions defined for sequencing purposes ("remain", "merge" and "heading then merge"):

- The "remain" instruction is expected to be the easiest to understand in terms of geometry of the procedure whereas the "heading then merge" instruction to be the most difficult to understand and probably to perform as well.
- Furthermore, the "heading then merge" instruction leading to a "merge" after the resume action and the "merge" instruction leading to a "remain" after the merging waypoint, it is felt that the crew should become familiar first with "remain", then "merge" and finally "heading then merge".
- Also, the "merge" instruction is expected to be the most accepted by flight crews because it should be the least time-critical: the spacing does not need to be acquired instantaneously, but within some time (i.e. when target at waypoint).

Note: The "heading then remain" instruction was not simulated as its usefulness has not been tested from a controller perspective.

The second set of hypotheses deals with the flight phase in which the spacing instruction is given (in cruise or in "initial descent"):

- In merging situations, cruise phase is expected to be less demanding for two reasons: first the situation involves two aircraft in stable conditions and second crews have time to establish the spacing as they are still quite far from the merging point.
- Descent phase is expected to require more monitoring and more speed actions because conditions are now evolving for both the target and own aircraft.

The third set of hypotheses deals with the impact of the spacing instructions on pilots function (PF and PNF):

- The spacing instruction is expected to increase both pilots monitoring load, but put a higher demand on the PF, who is directly involved in monitoring and maintaining the situation.
- The spacing instruction should also enable a reduction of PNF communication load in reducing the number of R/T messages.
4.3. EXPERIMENTAL PLAN

4.3.1. Independent variables

After considering the limited experiment duration (1 day per flight crew) and the hypotheses, the main independent variables were:

- Type of spacing instruction (“remain”, “merge”, “heading then merge”);
- Flight phase when initial spacing instruction is given (in cruise, in descent).

The pilot function was considered as a secondary independent variable.

The flight phase leads to identify two main typical situations that will be used for the three types of spacing instructions (Figure 2). These two scenarios enable two main comparisons: feasibility of acquiring the spacing and feasibility of maintaining it in the two flight phases.

![Figure 2: Scenario specificity](image)

4.3.2. Dependent variables

Given the experiment objectives, the following items correspond to dependent variables:

- Acceptability: subjective feedback on motivation, level of workload (NASA-TLX, number of actions) and interface usability;
- Activity: contextual and temporal analysis of speed actions, magnitude of speed actions;
- Effectiveness: spacing accuracy.
4.3.3. Experiment run plan

Because of limited duration of the experiment, only a very short training could be provided. This led us to gradually introduce the different applications according to their complexity (from the simplest to the most complex): “remain”, “merge”, “heading then merge”. For a typical day, each pilot plays one of each type of spacing instruction. Each type of spacing instruction is practised as pilot flying (PF) by both pilots: note that two different exercises were used to measure twice the same type of spacing instruction. The experiment objectives led to a 3×2 design: type of application (“remain”, “merge”, “heading then merge”) × flight phase (cruise, initial descent). The experimental plan (six flight plans resulting from the combination of the two main independent variables) is presented below (Table 5).

Table 5: Run plan

<table>
<thead>
<tr>
<th>Runs</th>
<th>Spacing instructions</th>
<th>Flight phases</th>
<th>Pilot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Run 1</td>
<td>Remain</td>
<td>Cruise</td>
<td>PF</td>
</tr>
<tr>
<td>Run 2</td>
<td>Remain</td>
<td>Descent</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 3</td>
<td>Merge OKRIIX</td>
<td>Cruise</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 4</td>
<td>Merge MEL</td>
<td>Descent</td>
<td>PF</td>
</tr>
<tr>
<td>Run 5</td>
<td>Heading then merge OKRIIX</td>
<td>Cruise</td>
<td>PF</td>
</tr>
<tr>
<td>Run 6</td>
<td>Heading then merge MEL</td>
<td>Descent</td>
<td>PNF</td>
</tr>
</tbody>
</table>

4.4. EXPERIMENTAL DESIGN

4.4.1. Simulation programme

The simulation took place between May 15\textsuperscript{th} and 22\textsuperscript{nd}. For each crew, the simulation programme covered a general briefing, an initial training and the measured runs with the spacing instruction. A general debriefing concluded each session. In order to perform the full program with 6 runs, each session lasted 1 day per crew.

4.4.2. Simulated environment

In order to investigate on the spacing task with regards to the flight phase in which the instruction is given, flights included end of cruise and descent down to the IAF. The flights were Paris Orly arrivals, started approximately 180NM from IAF (MEL) and lasted about 25 minutes. The figure below (Figure 3) describes the simulated airspace and the trajectories of the instructed and target aircraft. To be consistent with the use of spacing instruction made by the controllers during the previous ground experiments, the spacing instruction was given from 65 to 125NM from IAF in “cruise” scenarios and from 50 to 60NM from IAF in “descent” scenarios. The initial spacing for “remain” and “merge” instructions was slightly superior to 8NM. The initial spacing for “heading then merge” instruction was slightly inferior to 5NM.
To have comparable results from one crew to another, scenarios were scripted for both the instructed and the target aircraft (see the annex in § 2.2 for detailed scripts). The target aircraft was under conventional control and received a speed reduction. The target was simulated through a simple traffic generator (PLUME - Pilotage Limité à l'Utilisation des Moyens Existant) and the target actions (descent, speed reduction) were performed in real-time by a pseudo-controller according to the scripted scenario. The advantage of PLUME was the ease of use: stand-alone system with database and flight plans easily modifiable and interactive actions on altitude, speed and routing. The main drawback was the simplified aircraft model (too high and non modifiable descent rate).

The limited realism of the simulation environment should be noted: it is a part-task experiment with rather short flights; the cockpit simulator only features automatic related instruments with no external view, no party line and no TCAS display.

### 4.4.3. Spacing procedures

As previously described, the spacing task is divided into three distinct phases:

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

To meet the experiment objectives, three types of spacing instructions were used: “remain”, “merge” and “heading then merge”. For each instruction, the crew was tasked to adjust speed to acquire and maintain the spacing, following the graphical indications.
More precisely (Figure 4):

- For “remain”, target and instructed aircraft are following the same trajectory. The pilot is tasked to adjust speed to acquire and maintain the current spacing.

- For “merge”, target and instructed aircraft should be direct to the merging point; if it is not the case when the instruction is given, it is implicit in the merge that the pilot should perform a direct first. The pilot is tasked to adjust speed to acquire the spacing when the target is over the merging point. Once the target has passed the merging point, the “merge” becomes a “remain”.

- For “heading then merge”, target and instructed aircraft are direct to the merging point. The pilot is tasked to select a given heading until the spacing predicted at waypoint is reached. Once the spacing is acquired, the pilot is tasked to initiate a resume direct to the merging point, and adjust speed to maintain the spacing. Note that after the resume, the “heading then merge” becomes a “merge”.

To ensure a smooth and stable behaviour (in particular with multiple aircraft in a sequence) and avoid many speed adjustments, it was indicated that the pilot should not acquire the spacing before the target passed the merging point. During the “Assess feasibility” phase, a suggested ground speed is computed and displayed on the MCDU so as to meet the desired objective of spacing for “merge” and “remain”. It should be stressed that, the pilot is not authorised to modify route or change altitude, unless explicitly instructed by the controller. Note that the choice of the descent mode was left up to pilot preference: open descent, managed descent or vertical speed.

![Figure 4: “Remain”, “merge” and “heading then merge” applications](image)

### 4.4.4. Flight crew tasks

The flight crew was tasked to perform an automatic flight and other usual tasks, namely communications with ATC, checklist, operational flight plan, ATIS and briefing. It should be noticed that there was no automatic guidance function (i.e. no coupling to the autopilot or to the Flight Management System): the speed adjustments were manual.

In the experiment, flight crews were asked to perform the spacing task (speed adjustments through FCU) in addition to their conventional flight tasks. Concerning the task distribution for spacing, it was suggested that the PNF would perform the input of data in the 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 instructions, the target aircraft was under conventional control (i.e. not itself "spacing" instructed). ATIS, charts, checklists and operational flight plans were provided.
4.5. SIMULATOR AND PILOT INTERFACE

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, Multifunction Control and Display Unit (MCDU), Flight Control Unit (FCU), throttle and a simplified Electronic Centralised Aircraft Monitor (ECAM) with Engine Display only. No external view is available.

![Figure 5: Cockpit simulator](image)

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. On the ND, the ASAS features are:

The display cues can be divided into (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. 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.

- **Required spacing:** represented by an arc of circle (in magenta).

- **Predicted spacing:** A broken arrow with an arc, it indicates the position on the trajectory where the spacing will be acquired.

- **Data block** displaying among others, target ground speed and closure rate.
Tolerance margins were set to +/-1NM. A colour coding was used to highlight drifting situations, i.e. every time the spacing was outside the tolerance margin. No speed advisory was provided during the “acquisition” and “maintain” phases.

ADS-B capabilities were simulated. Target state vectors (position and velocity) were transmitted periodically (every 1 second) and received onboard cockpit simulator.

More details are provided in the pilot handbook (CoSpace, 2002a).

4.6. DATA COLLECTION, PRE-PROCESSING AND ANALYSIS

4.6.1. 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 items, including the use of the NASA Task Load Index (NASA-TLX) for workload assessment;
-Debriefings items.

Data collection method, occurrence, relevance and attributes are summarised in Table 6. Details about the system recordings are presented in the annex.
### Table 6: Data collection method and data attributes

<table>
<thead>
<tr>
<th>Method/tool</th>
<th>Metrics concerned</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre run data</strong></td>
<td>Questionnaires</td>
<td>All, but at a high level</td>
</tr>
<tr>
<td></td>
<td>Observations</td>
<td>Acceptability, cues about human activity, efficiency and safety</td>
</tr>
<tr>
<td></td>
<td>System recordings</td>
<td>All, at a detailed level</td>
</tr>
<tr>
<td></td>
<td>Questionnaires</td>
<td>All, at a more detailed level</td>
</tr>
<tr>
<td></td>
<td>NASA-TLX</td>
<td>Acceptability (workload)</td>
</tr>
<tr>
<td><strong>Post run data</strong></td>
<td>Debriefing</td>
<td>All</td>
</tr>
</tbody>
</table>

### 4.6.2. Data pre-processing

#### 4.6.2.1. Period of analysis

We considered as a relevant period of analysis the period from the start to the end of spacing instruction.

#### 4.6.2.2. Data verification

Prior to analysing system data recorded during simulation runs, a verification process took place. It consisted in filtering spacing value jumps. They were mainly due to some irregularities in transmissions of target state vectors and also to trajectory deviations when passing waypoints. It should nevertheless be noted that those jumps in spacing value were very fugitive and therefore often imperceptible; in any case, they did not impact pilot actions.

### 4.6.3. Data analysis

Objective and subjective analyses were conducted on data considering the spacing application and the flight phase.

The objective analyses consisted in two parts:

- A quantitative analysis consisted in automatic processing of relevant data to provide statistical figures.
- An (operational) expert analysis helped understanding flight events. This corresponds to a qualitative analysis.

The subjective analysis performed is based on various sources of information. The first source is the observations made during the runs complemented with pilots comments during and after the runs. The second source is the questionnaires given to the pilots before, during, and after the simulation. Post runs questionnaires (given during the simulation at the end of each run) included the NASA-TLX rating sheet. The third source is the final debriefing.

A sample of each questionnaire is presented in the annex.
4.7. PARTICIPANTS

5 crews (of 2 pilots each) took part in the experiment. 1 crew was composed of 2 test pilots from Airbus and the 4 other crews were composed of 8 French airlines pilots. Both test pilots and 1 French airline pilot participated in the November'00 experiment (EACAC 2001b). Among the 10 participants, 3 were captain and 7 first officers. Motivation to participate was assessed with a 4 values scale, going from 1 (very low) to 4 (very high). Most of them rated 4, while 2 rated 3. The overall “motivation” mean value is 3.8.

The age distribution is as follows:

Table 7: Participants age distribution

<table>
<thead>
<tr>
<th>Age</th>
<th>&lt;30 years</th>
<th>[30-35] years</th>
<th>&gt;35 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pilots</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

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

Table 8: Participants experience in flying Airbus aircraft and in flying in general

<table>
<thead>
<tr>
<th>Experience</th>
<th>&lt;3 years</th>
<th>[3-5] years</th>
<th>&gt;5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flying Airbus aircraft</td>
<td>3</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Flying in general</td>
<td>0</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

4.8. RESULTS

4.8.1. Factual data

6 runs per day, for 5 crews were initially planned. Because duration of initial briefing and training session had been underestimated, it was decided to skip the run with “remain” application in descent, throughout the May’02 experiment. Technical problems led to skip another run with one of the crews. Consequently, a total of 24 runs (out of the 30 initially planned) were actually measured (Table 9).

Table 9: List of measured runs

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Notation</th>
<th>Planned</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remain in cruise</td>
<td>RB</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Remain in descent</td>
<td>RB_OK</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Merge in cruise</td>
<td>MB_OK</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Merge in descent</td>
<td>MB_MEL</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Heading then merge in cruise</td>
<td>HMB_OK</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Heading then merge in descent</td>
<td>HMB_MEL</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
4.8.2. Design and feasibility

Simulation environment: The simulation realism was felt low, and the display of TCAS traffic and the party line were felt necessary. A point often raised by pilots was the inaccuracy of the target aircraft performance model (managed by a simplified traffic generator). For example, the speed reduction of the target aircraft in descent was much too slow and required to start deceleration at FL150 to be at 250kt at FL100 (whereas a real target aircraft would do it at FL120). Also, the pilots made comments on the target descent rate which was too high and could not be modified. As a result the difference in altitude between both aircraft increased, resulting in an indicated airspeed (IAS) reduction of the spacing instructed aircraft. Nevertheless, it did not impact the results as the pilots were able to maintain spacing.

Procedure: In general, the procedures, the phraseology and the task distribution were accepted. However some details were evoked. Typically, pilots did not appreciate the implicit “direct to” instruction included in the “merge”.

Suggestions for future experiments: Some interface improvements were required to reduce pilot workload (essentially the provision of the required speed in IAS on the ND). Flight crews were interested in assessing spacing in a more realistic context. Coupling with the auto-pilot was a strong demand.

4.8.3. Acceptability

4.8.3.1. Motivation to use the new instruction

During each individual crew debriefing, pilots stressed the positive aspect of taking an active part in the management of the spacing (be in the loop) and gaining a better understanding of the situation (with respect to the preceding aircraft). In addition, they mentioned that spacing instructions would probably enable more anticipation (be less in a reactive position) and an optimised management of their flight. However, they clearly stressed that a new task is added in the flight deck, with a potential risk of workload increase.

Among the 10 pilots, 4 felt that the spacing task was acceptable with current information displays, while 6 insisted on the need for a managed mode (i.e. spacing task coupled to the auto-pilot).

4.8.3.2. Usability of interface

The spacing display (the arc of circle) was not usable with every range. To provide relevant information, it required small range to be selected. In terms of assistance, they acknowledged the usability of the existing interface, but requested additional guidance cues such as spacing trend, resume advisories, speed bug, and eventually a fully managed (coupled) mode. In addition, some pilots stressed that the use of ASAS MCDU page should not be necessary during the spacing “acquisition” and “maintain” phases. All required information should be available on the ND.
4.8.3.3. **Workload**

Pilot workload was mainly assessed through the NASA-TLX which addresses the following dimensions:

- **Mental demand** for both PF and PNF was similar for the first two runs. Then it decreased for the PNF but slightly increased for the PF, especially for the first "heading then remain" run. The **temporal demand** remained at an acceptable level for the PF for each scenario. For the PNF, it slightly increased for the second run, but remained acceptable. Despite an increase for the second run for the PNF, the **physical demand** was low for both pilots and for all scenarios. Similarly, for both pilots and all runs the **performance** level was perceived as very high, except for the PNF for the second run. For both pilots, despite the increasing complexity induced by the run plan (i.e. scenarios get more and more complex), the perceived **effort** decreased with practice. For both pilots and for all scenarios, the **frustration** level was low. This reflects that despite the perceived mental and temporal demand the pilots were happy with their performance.

![Figure 7: NASA-TLX scores](image-url)
**Synthesis on acceptability:** Flight crews perceived benefits introduced by the spacing task, typically the active part they take in the management of the spacing and the better understanding of the situation. Additional support to perform the spacing task, through improved interface is requested (speed advisory for manual mode or a managed mode). Despite a higher mental and temporal perceived workload for the pilot flying, the workload is described as acceptable by both pilots.

### 4.8.4. Activity

Whereas the impact of spacing task on the overall activity is an important goal of the study, the present analysis focused only on the performance of the spacing task itself, in isolation from other conventional flight tasks. Impact of the spacing task on other flight tasks will be addressed later in the project. To address the spacing task, we looked globally at the speed profile for each run, defined a speed action, analysed the temporal distribution of speed actions, and also the magnitude of speed variations.

For each run, we looked at the aircraft speed profiles in time to have a clearer global picture and to visualize the run characteristics on a temporal basis. For each flight, we plotted events on the speed profile curves. Two examples are presented for illustration purpose. On the first example (Figure 8), the early speed reduction followed by an acceleration reflects that the resume action direct towards the merging waypoint (DIR TO) was initiated slightly too early. Then, the speed reduction was regular during the descent, performed in the open descent mode (OP DES). On the second example (Figure 9), the resume action (DIR TO) took place on time. However, we notice that the start of descent was performed in the open descent mode (OP DES) and that the crew switched to the managed descent mode (DES) before getting back to an open descent. The speed profiles provided a first feedback on pilots handling of the speed during the spacing task. Typically, excessive speed reduction, possibly followed by corrective speed increase are visible. The analysis led to refine metrics, such as the number, the duration and the frequency of speed actions (see examples in the annex).

![Figure 8: Example of a speed profile in a heading then “merge” scenario. Dark line represents the selected speed and the light one the actual airspeed. The x axis is a time line. The resume action is indicated by a DIR TO label. The selection of the descent mode is indicated by the OP DES label.](image-url)
To get an insight on the flight crew activity, we analysed the speed actions necessary to achieve such spacing. The definition of a speed action was not straightforward. Indeed, for every speed changes on the FCU, the system recorded each intermediate speed values. Typically, when the pilot reduced speed from 310 to 300 knots, the system recorded 10 speed values (309, 308, 300). To reflect speed actions, we needed to aggregate that data and looked at the number of actions detected when setting various inter-actions periods. Typically, we defined that if the period between two speed changes recorded in the logs was greater than the defined aggregation time, the second speed change recorded would belong to a new speed action.

The aggregation time was tested for values from 2 to 16 seconds. When set to 2 seconds, we counted 18 speed actions, whereas we counted 10 speed actions when set to 16 seconds. An aggregation time of 5 seconds totals 14 actions and seems to be an acceptable period as mean and max values seems to get stable (Figure 10). It shall be noted that with this analysis the duration of actions is not taken into account.
In the two examples, the overall number of speed actions is similar (13 and 11 actions per run of similar duration). For each scenario, we analysed the average number of speed actions per run (Figure 11). Less speed actions were performed during the MB_MEL scenario (“merge”, in descent phase), which was expected to be more demanding. The respective duration of runs explains the difference between average numbers of speed actions. Typically, for the MB_MEL runs, period of analysis lasted around 400 seconds, whereas for MB_OKRIX runs it lasted about 650 seconds. To reflect comparable results, we investigated the average number of speed actions per minute for each scenario (Figure 12). Mean value is between 1 and 1.5 action per minute. However, the figures vary as a function of the flight crew considered. The number can double for a same scenario: typically, it ranges from 0.6 to 1.1 for RB scenario, from 1.1 to 1.7 for MB_OK, from 0.8 to 1.6 for MB_MEL, from 0.6 to 1.2 for HMB_OK and from 0.7 to 1.5 for HMB_MEL. Apart from the MB_OK scenario, results show that the mean number of speed actions is below 1 per minute. The order of runs could explain why the MB_OK scenario required more actions per minute.

To relate speed actions to flight crew activity, we put them back in their context. We analysed the temporal distribution of speed actions and completed it with various events occurrence. Distribution was processed for each run (see the annex). The distribution was then computed for each scenario (Figure 13 to Figure 17). Indeed, even though we could identify same events occurring during every flight, their time of occurrence depended on the scenario. The analysis took into account two phases temporarily leading to not stable situations: the target descent and the target speed reduction. These two phases are delimited by four events: “target descent” by target initial descent and own initial descent, and “target speed reduction” by target initial speed reduction and target reaching 250 knots. Not surprisingly, results show in each scenario that changes of target state trigger speed adjustment in the cockpit. In some cases, up to five actions per minute were observed, which raises the issue of workload and compatibility with other flying tasks. However, our definition of an action might need to be reconsidered: typically, automatic counting of actions based on our 5 second period criteria does not enable the distinction between one slow change of speed values and two rapid successive changes. This definition of what is an action and how to measure it need further investigation.
Figure 13: Temporal distribution of speed actions. “Remain” scenario (RB).

Figure 14: Temporal distribution of speed actions. “Merge” in cruise scenario (MB_OK).

Figure 15: Temporal distribution of speed actions. “Merge” in descent scenario (MB_MEL).

Figure 16: Temporal distribution of speed actions. “Heading then merge” in cruise scenario (HMB_OK).
Beyond number and distribution of actions, we also investigated the magnitude of speed variations. Distributions for each scenario are presented in the annex. Because distribution for each scenario had similar curves, we computed the average distribution for all scenarios (Figure 18). Results show that most speed actions (65%) correspond to speed adjustments within –15 and +5kt rather than to large changes. However, some large changes can be observed (more than 40kt). This would need to be carefully analysed since this may impact both flight crew and controller workload (by possibly requiring more monitoring) and flight efficiency. This may also have an impact on the following aircraft (if any), and eventually create oscillatory effects on the whole sequence of "spacing" instructed aircraft (if any).

**Figure 17: Temporal distribution of speed actions. “Heading then merge” in descent scenario (HMB_MEL).**

**Synthesis on spacing tasks performance:** The analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is below 1.5 per minute. No difference was found across experimental conditions (type of spacing instruction and initial flight phase of the target). Differences were higher between pilots in particular for the min and max number of speed actions. Temporal distribution of speed actions provides a contextual understanding of their occurrence. In most cases, and in all experimental conditions, speed actions are triggered by modification on target (start of descent and speed reduction to 250kt). In terms of magnitude, 65% of speed actions correspond to rather small adjustments (between -15kt and +5kt).

**Figure 18: Average distribution of magnitude of speed variations. All scenarios.**
4.8.5. Effectiveness

In the present experiment, effectiveness of the spacing instruction was assessed through the spacing accuracy measure.

For each run, we analysed the achieved spacing profile. For illustration purpose, two spacing profiles, corresponding to the speed profiles presented previously (Figure 8 and Figure 9) are displayed on Figure 19 and Figure 20. It can be observed in the first one that although the resume action was initiated slightly too early, the spacing was achieved within +/-0.2NM with regular speed reduction during the descent. In the second example, although the resume action took place on time, the spacing varied within +/-0.8NM.

For each scenario, we analysed the spacing deviation at two different times: at the end of the “acquisition” phase (Figure 21) and at the end of the spacing task (Figure 22). The end of the “acquisition” phase corresponds to 2 minutes after instruction for the “remain” scenario and to the target reaching the merging point for “merge” and “heading then merge” scenarios. The mean value integrating all runs is also presented on each figure. It shall be reminded that flight crews were asked to maintain spacing within tolerance margins set to 1NM, i.e. maintain spacing between 7 and 9NM. However no explicit constraint was put on the expected spacing accuracy. At the end of the “acquisition” phase, the average spacing deviation is below 0.25NM for all scenarios. It is even around 0.10NM for the “remain” and the two “heading then merge” scenarios. When looking at extreme values, one can notice not only large deviations (still below 0.6NM) but also very small ones (close to 0NM).
At the end of the spacing task, the average spacing deviation for all scenarios is between 0.1 and 0.3 NM. Again, extreme values are lower than 0.6 NM and for some cases close to 0 NM. It shall be stressed that pilots did not use the whole tolerance margin, but rather aimed at the exact spacing.

![Diagram](attachment:image1.png)

**Figure 21:** Spacing deviation at the end of the “acquisition” phase.

![Diagram](attachment:image2.png)

**Figure 22:** Spacing deviation at the end of the spacing task.

Even though figures at the defined end of the “acquisition” phase are positive, it shall be stressed that it happened that “acquisition” phase ended earlier in “merge” scenarios. Typically, some pilots tried to acquire the spacing earlier than the fixed constraint. To go further and identify the average spacing value that can be maintained, we analysed the distribution of both average and maximum spacing deviation during the “maintaining” phase for each scenario (see the annex). To exclude the “acquisition” phase, we analysed the average time necessary to acquire the spacing within 0.3 NM. This led us to define the beginning of the “maintaining” phase 150 seconds after the activation of the spacing instruction (i.e. after the PNF presses the "INSERT" key). Whereas average deviation provides information about what is generally achieved during the “maintaining” phase, maximum deviation shows worst situations. It shall be noted that we consider the deviation value and not its duration. The distribution of average spacing deviation suggest two strategies: one consists in achieving the exact required spacing, whereas the other consists in using the tolerance margin. The distribution of maximum spacing deviation show that even in the worst case flight crew “remain” within the tolerance margins (set to +/-1NM), despite the basic assistance and the non-coupled mode.

![Diagram](attachment:image3.png)

**Figure 23:** Distribution of spacing deviation (max, max at 95% and average) during “maintaining” phase (all scenarios)
To go further than identifying two spacing strategies, we investigated whether there was a correlation between the strategy implemented and the spacing achieved. We analysed the distribution of average number of speed actions per minute as a function of the average spacing deviation achieved (Figure 24). One assumption was that more accurate spacing would require more actions (i.e. speed adjustments). This is not confirmed by the results, and no clear trend emerges. Correlation can be made neither when considering spacing type nor target attitude (in cruise or in descent). It is not clear at this stage if this results from the experiment set-up (e.g. small sample size, sensitivity to initial conditions) or from the measures being simply not appropriate (e.g. use of average or maximum spacing, number of actions).

**Figure 24: Average number of speed actions against average spacing deviation (for all applications and for each spacing type). RM, MB, and HMB denote respectively “remain”, “merge” and “heading then merge” applications, while OKR(IX) and MEL are the converging point (for OKRIX, the target aircraft is in descent).**

**Synthesis on spacing accuracy:** Despite the basic assistance and the manual mode, pilots could in all conditions maintain the required spacing within tolerance margin (+/- 1NM). Results suggest two strategies: aiming at the exact required spacing value or aiming at staying within the tolerance margin. No correlation between these two strategies and their respective cost in terms of speed actions could be found.

**4.9. CONCLUSION AND NEXT STEP**

The objectives of the May’02 experiment were to investigate the feasibility of three spacing instructions (“remain”, “merge” and “heading then merge”), including usability of interface, and to get a first insight on flight crew activity and effectiveness. Five flight crews participated during 1 day each. Flight crews were tasked to acquire and maintain the spacing with a defined tolerance of +/- 1 NM, from cruise to initial approach fix. The target was initially either in cruise or in descent.

General comments were positive and flight crews perceived benefits by the active part they took in the management of the spacing and the better understanding of the situation. Despite a higher mental and temporal perceived workload for the pilot flying, the workload is described as acceptable by both pilots.
In terms of interface, limited assistance was provided: information on current spacing, required spacing and closure rate was available on the navigation display. However, the calculation of the appropriate speed enabling the spacing to be maintained was left up to the pilots. The flight crews requested additional support through improved interface, mainly speed advisory for manual mode and a managed mode.

In terms of effectiveness, flight crews managed to maintain the spacing within an acceptable tolerance margin of +/-1 NM.

Two hypotheses were made regarding the impact of the independent variables (type of spacing instruction and flight phase) on flight crew activity. First, it was assumed that the type of spacing instruction would have an impact on the number of actions and on the monitoring demand. “Remain” was expected to be less demanding than “merge” and “heading then merge”. Second, the flight phase was assumed to have an impact on the number of actions and monitoring demand. The cruise phase was expected to be less demanding than the descent phase. However, none of these hypotheses could be verified. No trend could be observed. The impact seems to be more related to inter-individual differences than to independent variables.

Limitations of the experimental design should be reminded. The short duration of experiment limited the size of the sample. Whereas the experiment provided information about how 5 crews performed spacing in 5 conditions, no statistical test can be carried out. In addition, unexpected variability was experienced. First, despite the instruction to merge “when target is at the waypoint”, some crews decided to acquire the spacing as soon as possible. Second, the descent mode, left to flight crew discretion, happened to be an additional variable not identified in the experiment plan.

In the next experiment, two main elements will be considered. First, better support by adding new features: speed cues and spacing trend. Second, strengthen experimental design by limiting the number of independent variables and controlling as much as possible variables which may alter the results.
5. DECEMBER’02 EXPERIMENT

5.1. EXPERIMENT OBJECTIVES

The objectives of the present experiment were:

- To assess relation between spacing tolerance and flight crew activity, effectiveness and safety;
- To assess usability of improved interface;
- To identify if and how eye movement analysis could be used to assess impact on monitoring.

5.2. HYPOTHESES

Two sets of hypotheses were defined based on the experiment objectives, the principles of airborne spacing and flight crew activity:

The first hypothesis deals with the tolerance margin: the smaller the tolerance margin the higher the workload in terms of both monitoring and number of speed adjustments.

As for May’02 experiment, the second set of hypotheses deals with the impact of the spacing instructions on pilots roles (PF and PNF):

- The spacing instruction is expected to increase both pilots monitoring load, but put a higher demand on the PF, who is directly involved in monitoring and maintaining the situation.
- The spacing instruction should also enable a reduction of PNF communication load in reducing the number of R/T messages.

5.3. EXPERIMENTAL PLAN

5.3.1. Independent variables

Given the experiment objectives, the main independent variable was the tolerance margin. Three values were defined: +/-1NM, +/-0.5NM and +/-0.25NM. The pilot function was considered as a secondary independent variable.

To limit the number of independent variables, it was decided to focus on the “merge” instruction most used by the controllers during the ground experiments.

Both pilots also flew a conventional flight for baseline purpose. In addition, this flight helped pilots comparing conditions without and with spacing instructions.
5.3.2. Dependent variables

Following the validation framework described previously (Table 4), we looked more specifically at the following dependent variables:

- Acceptability: subjective feedback on motivation, level of workload (NASA-TLX, number of actions) and interface usability;
- Activity: subjective feedback, contextual and temporal analysis of speed actions, magnitude of speed actions;
- Effectiveness: spacing accuracy;
- Safety: subjective feedback, losses of spacing, large speed magnitude.

5.3.3. Experiment run plan

The experiment objectives led to a 3×2 design: spacing tolerance margin (1, 0.5, 0.25NM) × function (PF, PNF). In addition, for baseline purpose, each pilot flew once as PF without spacing instruction. The resulting experimental plan is presented below (Table 10). In order to diversify scenarios, some flights had for destination Paris Orly (LFPO) and others Paris Charles De Gaulle (LFPG).

Table 10: Run plan

<table>
<thead>
<tr>
<th>Runs</th>
<th>Conditions</th>
<th>Destinations</th>
<th>Pilot</th>
<th>Eye movement measurement³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>Without</td>
<td>LFPG</td>
<td>PF</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 2</td>
<td>+/-1NM</td>
<td>LFPO</td>
<td>PF</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 3</td>
<td>+/-0.5NM</td>
<td>LFPG</td>
<td>PNF</td>
<td>PF</td>
</tr>
<tr>
<td>Run 4</td>
<td>+/-0.25NM</td>
<td>LFPO</td>
<td>PF</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 5</td>
<td>Without</td>
<td>LFPO</td>
<td>PNF</td>
<td>PF</td>
</tr>
<tr>
<td>Run 6</td>
<td>+/-0.5NM</td>
<td>LFPO</td>
<td>PF</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 7</td>
<td>+/-1NM</td>
<td>LFPG</td>
<td>PF</td>
<td>PNF</td>
</tr>
<tr>
<td>Run 8</td>
<td>+/-0.25NM</td>
<td>LFPG</td>
<td>PNF</td>
<td>PF</td>
</tr>
</tbody>
</table>

5.4. EXPERIMENTAL DESIGN

5.4.1. Simulation programme

The simulation took place between December 5th and 18th. The daily programme covered a general briefing, an initial training and 8 measured runs, enabling pilots to alternate functions (pilot flying/not flying). A general debriefing concluded each day. On the 5th, 6th, 9th and 10th, sessions for crews who had participated to previous experiment (May’02) lasted 1 day per crew. On the 11th/12th and 17th/18th, the sessions lasted 1.5 day per crew. Half a day was dedicated to extended training session.

³ Eye trackers were used during only 2 days.
5.4.2. Simulated environment

The simulated environment was similar to the one used for the CoSpace November 2002 ground experiment and the scenarios were scripted accordingly to the use of the “merge” instruction made by controllers. Flights consisted of arrivals to Paris Orly (LFPO) and Charles De Gaulle (LFPG) from cruise to IAF (respectively MOLEK and OMAKO), and lasted about 25 minutes flight time. The figure below (Figure 25) describes the simulated airspace and the trajectories of the instructed and target aircraft. The runs started approximately 150NM from IAF. In LFPO scenarios, the spacing instruction was given at approximately 130NM from IAF and the initial spacing was approximately 10.5NM. In LFPG scenarios, the spacing instruction was given at approximately 120NM from IAF and the initial spacing was approximately 7.5NM. Flights to LFPO had a late descent whereas flights to LFPG had an early one.

Figure 25: Simulated airspace and trajectories

Following May'02 recommendations, effort was put on improving simulation realism. Each flight was "inserted" in a scenario previously recorded with an air traffic controller, thus providing realistic voice communications (and party-line) along with a display of TCAS traffic. In this scenario, an operational controller was managing 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, first the radio party-line included all the voice communications and in particular instructions for the cockpit simulator (except -of course- communications from cockpit simulator) and second when within range, the surrounding traffic was visible on TCAS display.
The other traffic was generated by MASS (Multi Aircraft Simplified Simulator) on the ESCAPE platform and recorded on a DIS (Distributed Interactive Simulation) manager. The advantage of MASS over PLUME used in May’02 was an increased realism in terms of target aircraft modelling, with a configurable descent rate and a more realistic speed reduction. Generating the scenarios nevertheless required a more demanding preparation and the use of an ESCAPE (Eurocontrol Simulation Capability and Platform for Experimentation) platform with one controller and two pseudo-pilots.

In addition to the flight plans used, controllers’ instructions for the eight scenarios were also scripted (content and time of occurrence) so that observers would be able to follow the progress of the runs. Detailed scripts are presented in the annex.

5.4.3. Spacing procedures

As for previous experiment, the spacing task is divided into three distinct phases:

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

During the experiment, only “merge” instructions were given. The crew was tasked to adjust speed to acquire and maintain the spacing, following the suggested airspeed. More precisely (Figure 26):

- Target and instructed aircraft are direct to the merging point. The pilot is tasked to adjust speed to acquire the spacing when the target is over the merging point. After the target passed the merging point, the “merge” becomes a “remain”.
- When in “remain”, target and instructed aircraft are following the same trajectory. The pilot is tasked to adjust speed to acquire and maintain the current spacing.

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

To ensure a smooth and stable behaviour (in particular with multiple aircraft in a sequence) and avoid many speed adjustments, it was clearly stated that the pilot shall aim at reaching the required spacing when the target passes the merging waypoint.

![Figure 26: “Merge” applications](image)
5.4.4. Requirement on descent mode

Following May’02 conclusions, particular attention was paid to the influence of the descent mode on the spacing instructed aircraft deceleration. Given the fact that scenarios consist in flight arrivals, most speed adjustments are decelerations occurring in descent, for which the influencing factors are numerous:

- Some of them are fixed variables at a given moment in flight: e.g. the aircraft and engine type, the weight, the centre of gravity and the altitude.
- Others may be modified by the crew: e.g. value of selected speed, descent mode and use of speed brakes.

To maintain the required spacing behind the target aircraft, the crew must select the appropriate speed but the time necessary to acquire that selected speed may vary greatly:

- In the managed descent mode (DES), priority is given to an optimum descent profile and the vertical speed is not modified to favour deceleration. Whereas in “open descent” mode (OP DES), the thrust is kept at idle and the vertical speed is modified as necessary to obtain the selected speed. Figure 27 shows a case where the deceleration in “open descent” mode is about three times stronger than in the managed descent mode.
- The deployment of speed brakes, adding drag to the aircraft, also has a strong effect on the deceleration. Figure 28 shows a case where the deceleration is five times stronger when using speed-brakes.

![Figure 27: Speed reduction in "open descent" versus "managed descent"](image1)

![Figure 28: Speed reduction performed with or without speed-brakes](image2)

The factors influencing the deceleration capacity also influence the performance of the spacing task and can be seen as variables in the experiment. 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.

Note: The use of speed-brakes was accepted to ensure realism in the simulation.
5.4.5. Flight crew tasks

The flight crew was tasked to perform an automatic flight and other usual tasks, namely communications with ATC, checklist, operational flight plan, ATIS and briefing. The scenario consisted in maintaining a given spacing (8NM) in a “merge” situation, through manual speed adjustments with the support of display cues. It should be noticed that there was no automatic guidance function (i.e. no coupling to the autopilot or to the Flight Management System): the speed adjustments were manual. Similarly to May’02, concerning the flight crew tasks distribution, it is suggested that the non-flying pilot (PNF) would perform the input of data in the MCDU and that the flying pilot (PF) would make the necessary speed adjustments to perform the spacing task. Both pilots would monitor the spacing.

During runs with spacing instructions, the target aircraft was under conventional control (i.e. not itself "spacing" instructed). ATIS, charts, checklists and operational flight plans were provided. In the experiment, flight crews were asked to perform the spacing task (speed adjustments through FCU) in addition to their conventional flight tasks (e.g. ATIS, briefing, operational flight plan).

5.5. SIMULATOR AND PILOT INTERFACE

The cockpit simulator is the same as the one used in the May’02 experiment (see § 4.5). Some of the graphical ASAS features developed to support the spacing task on the ND were improved. Others were not modified: the predicted spacing (“broken arrow”), the target aircraft symbol and the reference line between ownship and target (Figure 29).

The majority of the new features originate from pilot suggestions. The arc of circle indicating the required spacing and the data block displaying among others the target ground speed and the closure rate were replaced by:

- **A spacing scale:** Positioned on the left of the ND, it indicates: current and required spacing, spacing trend and closure rate, and tolerance margins. 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 margins (e.g. 2x0.5 NM). The current spacing is indicated at the left of the scale (e.g. 8.1 NM). 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 larger or smaller than current spacing) when outside range. The closure rate (equivalent IAS) is indicated in green (e.g. + 7kt of relative IAS) 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. Tolerance margins are represented by amber rectangles. When the current spacing gets out the tolerance (i.e. required spacing symbol out of the spacing scale), caution situation will be detected.

- **A suggested airspeed:** Displayed at the bottom of the ND, the suggested Indicated Air Speed (IAS) corresponds to the speed that one should take in order to obtain spacing within a time:
  - necessary for the target to reach the merging point in “Merge”;
  - of 2 minutes to recover spacing once acquired,
  - of 5 minutes during the “acquisition” phase for “Remain”.


The suggested speed is displayed in green when feasible, but is replaced by dashes when outside the flight envelope.

- **ASAS pilot prompts**: Five new prompts have been introduced on the ND:
  - ‘stabilise speed’,
  - ‘direct to’,
  - ‘losing spacing’,
  - ‘unable delegation’.

![ASAS features on ND](image)

**Figure 29: ASAS features on ND**

As in May’02 experiment, ADS-B capabilities were simulated. Target state vectors (position and velocity) are transmitted periodically (every 5 seconds) and received onboard cockpit simulator.

For an extended description of the interfaces, see Pilot handbook (CoSpace, 2002b).

5.6. DATA COLLECTION, PRE-PROCESSING AND ANALYSIS

5.6.1. Data collection

In comparison with May’02 experiment, the same objective and subjective data were collected for measurement purposes.

Objective data were broadened to pilot eye movement recordings to analyse monitoring and scanning patterns (Figure 30). It consisted of recording position and duration of eye fixations on the following flight deck elements: primary flight display (PFD), navigation display (ND), and flight control unit (FCU), display control panel (EFIS CP), and multi control and display unit (MCDU).
Data collection method, occurrence, relevance and attributes are summarised in Table 11. Details about the system recordings are presented in the annex.

<table>
<thead>
<tr>
<th>Method/tool</th>
<th>Metrics concerned</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
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<td></td>
<td></td>
</tr>
<tr>
<td>Questionnaires</td>
<td>All, but at a high level</td>
<td>Subjective Qualitative</td>
</tr>
<tr>
<td>Observations</td>
<td>Acceptability, cues about human activity, efficiency and safety</td>
<td>Subjective Qualitative</td>
</tr>
<tr>
<td>System recordings</td>
<td>All, at a detailed level</td>
<td>Subjective Qualitative</td>
</tr>
<tr>
<td>Continuous data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eye tracker</td>
<td>Acceptability (workload)</td>
<td>Subjective Qualitative</td>
</tr>
<tr>
<td>Questionnaires</td>
<td>All, at a more detailed level</td>
<td>Subjective Qualitative/Quantitative</td>
</tr>
<tr>
<td>Post run data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NASA-TLX</td>
<td>Acceptability (workload)</td>
<td>Subjective Quantitative</td>
</tr>
<tr>
<td>Debriefing</td>
<td>All</td>
<td>Subjective Qualitative</td>
</tr>
</tbody>
</table>

5.6.2. Data pre-processing

5.6.2.1. Period of analysis

Pre-processing was made to restrict the analysis to a same period for all runs: starting at the validation of the spacing instruction and ending when the situation is stabilised. We considered that the situation was perfectly stabilised when both the closure rate and the spacing deviation were near 0. According to that criterion, 22 runs out of the 30 analysed were perfectly stabilised at the end of the run (Figure 31).
Finally, the duration of the periods of analysis was checked: from 898 to 1093 seconds for the LFPO scenario and from 870 to 1007 seconds for the LFPG scenario. The periods of analysis had approximately the same duration across runs. Details about runs duration are presented in the annex.

5.6.2.2. Data verification

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

It consisted in filtering jumps in values clearly identified as system bugs (see Figure 32 for an example). Some of the bugs were due to irregularities in the DIS time-stamps; others were due to calculations occurring simultaneously to passing a waypoint. In all cases, they were fugitive and did not impact pilot actions.

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**Figure 32: Example of jump in values BEFORE and AFTER correction**

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Even though the run marked with a red arrow appears to be part of the outlying runs set, it is considered stabilised since the speed selected at the end of the spacing task is leading to a stabilised situation.
5.6.3. Data analysis

Analyses were conducted on data considering the spacing tolerance margin and the scenario (LFPO, LFPG).

The objective analyses consisted in three parts:

- A first quantitative analysis consisted in automatic processing of relevant data to provide statistical figures.
- A second quantitative analysis which consisted in processing eye movement data on some runs allowed investigating the feasibility and the use of such data.
- An (operational) expert analysis helped understanding flight events. This corresponds to a qualitative analysis.

The subjective analysis performed is based on various sources of information. The first source is the observations made during the runs complemented with pilots comments during and after the runs. The second source is the questionnaires given to the pilots before, during, and after the simulation. Post runs questionnaires (given during the simulation at the end of each run) included the NASA-TLX rating sheet. The third source is the final debriefing.

A sample of each questionnaire and the final questionnaire synthesis are presented in the annex.

5.7. PARTICIPANTS

7 crews (of two pilots each) took part in the experiment. 1 crew was composed of 2 test pilots from Airbus and the 6 other crews were composed of 12 European airlines pilots. Both test pilots and 6 airlines pilots participated in the May'02 experiment. Among the 14 participants, 7 were captain and 7 were first officer.

The age distribution is as follows:

<table>
<thead>
<tr>
<th>Age</th>
<th>&lt;30 years</th>
<th>[30-35] years</th>
<th>&gt;35 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pilots</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Experience</th>
<th>&lt;3 years</th>
<th>[3-5] years</th>
<th>&gt;5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flying Airbus aircraft</td>
<td>2</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Flying in general</td>
<td>1</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>
5.8. RESULTS

5.8.1. Factual data

8 runs per day, for 7 crews were initially planned. The use of eye tracker devices induced both delays and technical problems. As a result, 42 runs out of 56 planned were actually measured.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Planned</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>No spacing instruction</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>1NM margin</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>0.5NM margin</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>0.25NM margin</td>
<td>14</td>
<td>9</td>
</tr>
</tbody>
</table>

Eye tracker devices were used during two sessions. Even though it was planned to record both crew member eye movements, technical problems led to restrict the recordings to 1 crew member at a time.

5.8.2. Design and feasibility

Simulation environment: Compared to May'02 experiment, the realism has been improved. However, the radio quality (sound level, messages truncated) might still benefit from some improvements. Engine noise, typically during speed adjustment is also required.

Procedure: In general, the procedures, the phraseology and the task distribution were accepted. However some details were evoked. It happened under certain circumstances that the suggested IAS surprised pilots: typically, when far from the merging point and with a current speed greater than the target aircraft speed, the system could suggest the current speed to be maintained, even though the initial spacing is greater than the required one. The implicit “direct to” contained in the “merge” instruction disturbed pilots. In addition, differences in airline policies and procedures (operational documents, silent cockpit) should also be considered.

Suggestions for future experiments: Only few interface improvements were required. Typically, to reduce head down time, some pilots suggested the provision of additional warning when the target aircraft suddenly changes speed (e.g. 250kt reduction). Flight crews were interested in assessing spacing in approach, in degraded conditions (e.g. weather, emergency), in the case of long chains of "spacing" instructed aircraft and in a more realistic environment (full flight simulator). Coupling with the auto-pilot is a recurrent demand.
5.8.3. Acceptability

5.8.3.1. Motivation to use the new instruction

Among the 14 pilots, 10 felt that the spacing task was acceptable with current information displays, while 3 of them still insisted on the need for a managed mode (i.e. spacing task coupled to the auto-pilot). It shall be noticed that pilot acceptance has evolved positively since previous experiment (May’02). Because some of them took part in the previous experiment, it is difficult to assess if current concept and interfaces acceptance is due to familiarity with the simulation environment or to interface improvement. However, pilots participating for the first time in CoSpace experiments did not ask for coupling to the auto-pilot.

5.8.3.2. Usability of interface

Usability of the interface was mainly assessed through pilot comments during the experiments and item questionnaires. Whereas the MCDU is essential during the target selection phase, back-up information displayed during the spacing task is actually not perceived as useful by pilots. Their main source of information is the ND. The spacing scale was generally appreciated, described as intuitive and useful and well integrated in the scanning pattern by some pilots. Other thought they focused too much on it, especially in low tolerance cases (+/-0.25NM margin). The closure rate seemed less useful and usable. Compared to previous experiments where it was not available, the suggestion of an IAS seems to reduce the number of actions required. Pilots did appreciate the provision of suggested IAS on the ND. According to pilots, interface improvements seem to increase the interface usability.

Some messages currently displayed on the ND are requested on the PFD. More support is required to detect changes in target state. The relevance of the predicted spacing ("broken arrow") is questioned. The provision of information, more specifically of a speed bug on the PFD indicating the suggested speed is questioned. Even though it is required, it might lead to an increase of the focus on the PFD, and consequently to a reduction of the time spent scanning the ND.

5.8.3.3. Workload

Questionnaire items

In questionnaires, compared to today situations, the overall mental effort in the cockpit is rated “higher” (“much higher” for 2 pilots) at the PF position. At the PNF position, it is rated “higher” by 11 pilots and “lower” by 3 pilots. Nevertheless, the workload (including speed/heading changes) to acquire and maintain spacing is acceptable at both PF and PNF positions (at the most, only 3 pilots disagreed).

NASA-TLX ratings

NASA-TLX scores show similar results regarding the impact of spacing task on perceived workload. In terms of overall mental demand, the spacing task induces an increase for both pilot flying (PF) and pilot non flying (PNF): scores evolve from 22 in conventional situation for both PF and PNF to 40 in situation with spacing task for both of them. The impact of tolerance margin is more noticeable on the PF workload: reducing margins leads to increasing mental demand from 40 with 1 NM margin to 52 with 0.25NM margin (Figure 33). The margin has no impact on the PNF mental demand. This could be related to the fact that whereas both pilots are involved in monitoring the situation, the PF is in charge of adjusting speed to maintain the spacing.
Because smaller margins may lead to more adjustments, it seems consistent that the PF workload is perceived higher with smaller margins. With 1 and 0.5NM margins, workload remains acceptable as it is far from "effortful". However with 0.25 NM margin, it gets closer to "rather effortful". As a reminder, in May’02, with the “merge” scenario (1NM tolerance margin), both PF and PNF rated 50 for mental demand. It is possible that HMI improvements helped reducing mental demand.

Similarly, in terms of temporal demand (Figure 34), compared to conventional flight, the spacing task induces a small increase for both pilots: temporal load evolves from 3.5 to 5 on the 10 level scale. However, the temporal demand gets much higher for the PF than for the PNF with smaller tolerance margins: it increases up to 7.8 on the 10 levels scale. This could be related to the tighter monitoring and speed adjustments required to remain within acceptable limits. Whereas temporal demand seems acceptable with the 1 and 0.5NM margins, it seems not acceptable with the 0.25NM margin. In May’02, for the “merge” scenario, PF rated 5 and PNF rated 4 for the temporal demand. No changes are seen between May’02 and December’02 ratings.

Communication load

Note: To address communication load, we should have considered both communications with ATC (number, frequency and duration of R/T messages) and communications in the cockpit (number, duration, frequency of exchanges). However, given our experimental set-up we did not record communications. Only observer notes and questionnaires items give information about the communication load.

With the spacing task, pilots rated the communication load as lower at both PF and PNF position: communications with controllers are less frequent and shorter, whereas communications in the cockpit are more frequent or same as today, but shorter.
Monitoring load

Questionnaire items show that the monitoring load is perceived differently: some pilots think they focus on the new display cue (spacing scale), whereas other felt it was well integrated in their overall scanning pattern. The reduced tolerance margin (0.25) seems to induce more frequent monitoring. In general, pilots felt that too much time is spent monitoring the spacing especially when the target reduces to 250kt. One pilot suggested that the spacing task may be too demanding at the end of cruise and during the descent. In the maintain phase, one pilot suggested to add a warning when the difference between the current speed and the suggested speed is superior to a certain amount.

Synthesis on acceptability: The overall feedback was positive. Modification on the interface improved its usability. The increased workload with the spacing instruction is considered as acceptable. However the smallest tolerance margin (+/-0.25NM) induced higher perceived workload, especially for the pilot flying and was perceived as more demanding in terms of monitoring. Despite interface improvements, some pilots asked for a managed mode.

5.8.4. Activity

Similarly to May’02 experiment, the present experiment focused on the performance of the spacing task itself in terms of spacing acquisition and maintenance. Investigation of the impact of spacing tasks on other flight crew tasks will be the object of later experiment.

5.8.4.1. Acquire and maintain spacing

During debriefing sessions, pilots described how they analyse situations and decide on required actions. In terms of decision making process, the main sources of information used by pilots are the current spacing and the suggested speed. The process is described in three main steps: (1) estimate what is required (acceleration or deceleration) through comparison with the required spacing, (2) look at current spacing, at trend and at SUG_IAS, (3) compare with own IAS (on FCU), then on PFD. When carrying out the spacing task, pilots tend to listen to instructions given to their target, in order to anticipate actions (e.g. descent, speed reduction).

To assess the impact of spacing task on the pilot activity, we first describe this activity in relation with flight phases and events. During the simulation runs, aircraft evolve from cruise to initial approach fix. In terms of flight phase, we can identify cruise, initial descent (from the top of descent until exit level) and initial approach. Events marking these phases are level instruction (generally “descend flight level 100”) and target speed reduction when it reaches FL100. Considering the spacing task, we can distinguish three phases: target identification, spacing "acquisition" phase (between spacing instruction and target passing waypoint) and spacing "maintaining" phase (after the target has passed the waypoint).

During the runs we could notice different strategies: typically some pilots tried to acquire the spacing as soon as possible, whereas other followed the constraint that was to acquire it when the target was over the waypoint. This leads us to define three analysis periods during the spacing task: initial acquisition (between instruction and reaching of the required spacing value within tolerance margin), spacing maintaining until target is passing merging point, spacing maintaining once target has passed the waypoint. To avoid confusion, the last phase is called “remaining behind”.

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The first analysis consisted in analysing the respective duration of the “acquisition” and the “maintaining” phases during the theoretical “acquisition” period (i.e. between spacing instruction and target passing merging waypoint). Results (Figure 35) show that for both scenarios the duration of the “acquisition” phase gets smaller with larger margins. In other words, larger margins leads to reach sooner the required spacing. They also reflect the main difference between the two scenarios: in LFPG the spacing is initially quite existing (approximately equal to 7.5NM), while it needs to be established in LFPO (approximately equal to 10.3NM). Standard deviations are comparable in all conditions.

![Figure 35: Duration of “acquisition” phase, compared to duration of “merge” phase (including “acquire” and “maintain”)](image)

When comparing the distribution of acquisition duration as a function of conditions, we notice similar results (Figure 36 and Figure 37). For each scenario, the size of the tolerance margin influences the duration of the “acquisition” phase. Again, difference between the scenario appears: in LFPG, 20% of the time is spent acquiring the spacing, whereas 80% is spent maintaining it. In LFPO, where the initial spacing is much larger than the required one between 30% and 70% of the time is spent acquiring the spacing.

![Figure 36: Distribution of “acquisition” phase duration, as a function of tolerance margin (LFPG scenario)](image)
Similarly to previous experiment analysis, we looked at speed profiles (Figure 38 and Figure 39). Selected, current IAS and suggested IAS are displayed. In addition, spacing phases, own top of descent and target initial speed reduction are marked. Speed profiles for every run are presented in the annex.

Figure 37: Distribution of “acquisition” phase duration, as a function of tolerance margin (LFPO scenario)

Figure 38: Example of speed profile for a LFPO scenario, 0.5NM tolerance margin. 22 speed actions, including 3 on speed brakes were counted.
Speed profile, scenario LFPG, 0.5NM tolerance margin

![Speed Profile Diagram](image)

Figure 39: Example of speed profile for a LFPG scenario, 0.5NM tolerance margin. 21 speed actions, including 1 on speed brakes were counted.

Number of speed actions

Following May’02 results, we limited the analysis of speed actions to the average number of actions per minute. Globally, no strong difference is observed between conditions (Figure 40). Even though smaller margin seems to induce more numerous speed actions, the difference between conditions remains tight (1.7 actions per minute with 0.25NM margin against 1.3 actions per minute with 0.5NM margin and 1 action per minute with 1NM margins).

When analysing the average number of speed adjustments per minute in each phase (Figure 41), we notice two points: the “remaining phase” demands the most numerous speed adjustments, whereas the “acquisition” phase demands the less frequent adjustments. The same trend is observed for the three tolerance margins, even though the smaller one is the most demanding in terms of number of speed actions.

**Figure 40: Average number of speed actions per minute, for both scenario and all tolerance margins**

**Figure 41: Average number of speed actions per minute, as a function of the spacing phases**
Beyond the number of speed actions per se, we analysed the average period between successive speed actions. First, we looked at the temporal distribution of each successive speed adjustments (see examples in the annex). We identified 5 seconds as the minimum period between two actions. Below 5 seconds, as illustrated previously, successive actions are considered as 1. The comparison for a same scenario between tolerance margins does not show difference (see the annex). The same trend is observed: two main groups of periods are identified. In both scenarios (Figure 42 and Figure 43), we identify 1 grouping of smaller periods (smaller than 3 minutes) mainly linked to changes on target state and 1 grouping of large periods between actions (between 5 and 7 minutes).

![Distribution of periods between speed actions (LFPO)](image)

**Figure 42: Distribution of periods between successive speed actions (LFPO scenario)**

![Distribution of periods between speed actions (LFPG)](image)

**Figure 43: Distribution of periods between successive speed actions (LFPG scenario)**

To relate speed actions to flight phases, we looked at their temporal distribution (Figure 44 and Figure 45). In both scenarios, speed actions are triggered by target events (descent followed by speed restriction at exit point). The distribution also shows the difference between the two scenarios: in the LFPO scenario, the required spacing is initially reached (or almost reached for 0.25NM tolerance margin) and limited speed actions aim at maintaining it, whereas in the LFPG scenario, initial speed actions are needed to establish the required spacing. Distributions for each scenario, per tolerance margin and with a smaller time interval are presented in the annex.
The tolerance margins do not modify the shape of the temporal distribution. As illustrated on Figure 46, Figure 47 and Figure 48, increase in the average number of speed actions is observed at similar moment: in reaction to target descent and to target speed reduction. The “acquisition” phase is the least demanding in terms of number of actions, especially with 0.5 and 1NM margins. Acquiring the spacing usually requires 1 speed action, while maintaining it despite target events, such as descent and speed reduction requires many more actions. The main difference between tolerance margins is related to the average number of actions: smaller margins require more numerous actions. The same trend is observed for LFPG scenario. LFPG corresponding figures are presented in the annex.
Magnitude of speed actions

To address the potential impact of the spacing task in various conditions on the magnitude of speed actions, the overall magnitude of speed reduction between the beginning and the end of the scenario was first considered. Total magnitude figure includes both speed increase and decrease.

The analysis of the total magnitude of performed speed actions (Figure 49) shows two points. First, there is an inter-individual effect, as for a same scenario in same condition we notice large difference between the achieved total magnitude. In addition, it is difficult to correlate magnitude and condition, as in LFPO the average magnitude seems similar in extreme conditions (0.25 and 1NM) and larger in the 0.5NM conditions. In LFPG, the magnitude seems to decrease with larger tolerance margins.

The next step consists in comparing the total magnitude of performed speed actions with the expected speed reduction (denoted optimal magnitude) in order to assess if the spacing task in different conditions leads to excessive speed adjustments. Globally, aircraft started at flight level 280 or 300, speed 300kt and the scenario ended when situation was stabilised in terms of spacing, with target at FL100 or 90 and speed 250kt. The optimal magnitude is defined as the difference between the IAS of the spacing instructed aircraft at the beginning of the “acquisition” phase and the IAS it should have had ideally at this altitude to have a closure rate of 0 with the target at the end of the run.

The optimal magnitude varies from 49kt to 71kt. Results show that the magnitude of performed speed actions is more than twice the optimal magnitude value (Figure 50). However, these results should be interpreted carefully as the analysis does not identify variability due to pilot behaviour, to the suggested airspeed and to interaction between pilot behaviour and suggested airspeed. Results also show the strong variations existing between flight crews. Apart from the 0.25 condition in LFPO, results are comparable in both sectors. Typically, the same values are observed in both sectors for a same condition. Larger margin (1NM) seems to induce less deviation from the optimal magnitude of speed changes. However, strong variations between flight crews and limited number of runs limit the interpretation of results. The same analysis could have been done on runs excluding non stabilised ones. However, the filtering of non stabilised runs led to only one run left in one of the condition (LFPO 1NM).

![Total magnitude of speed changes](image)

*Figure 49: Total magnitude of speed changes (absolute values), between beginning and end of run*
Beyond the total magnitude of speed changes per run, we analysed the magnitude of each speed action.

First, we analysed the average speed magnitude. When considering the scenario, we notice similar results: the average magnitude of speed change correspond to a small speed adjustment, around 10 knots (Figure 51). The analysis of speed magnitude in the three spacing phases shows that the average magnitude is usually comprised between 10 and 15 knots in all phases (Figure 52). However, standard deviations show cases of larger average magnitude, up to 25 knots. Further analysis is required to understand what caused these larger changes.

To go a step further, we looked at the distribution for the two scenarios, for all tolerance margins (Figure 53 and Figure 54). Average figures show that in both scenarios, with all tolerance margins, and during all three phases, most of the speed actions are small adjustments comprised between -10 and +10 knots. Flight crews seem to be in a position to regularly perform small speed adjustments rather than large speed changes. This is a positive indication since large speed changes could be detrimental to flight efficiency and to the quality of the spacing. Typically, in case of chains of aircraft one has to envisage the consequence of large speed changes on the last aircraft. However, too numerous small speed adjustments could induce too much focus on the speed adjustments.
Then, we analysed the distribution for each tolerance margin and for both scenarios (Figure 55, Figure 56 and Figure 57). Note that distributions for each scenario, per tolerance margin and with a smaller time interval are presented in the annex. The curves have similar trends with the three tolerance margins. Most speed actions correspond to small adjustments.

At last, we looked at the distribution of speed adjustments during the three main spacing phases (Figure 58, Figure 59 and Figure 60). Because no difference was noticed between tolerance margins, the analysis considers together the three conditions.
LFPG figures are presented in the annex. Results show that the magnitude does not vary as a function of the spacing phase: large magnitudes are not more frequent in one of the phase than in the other. Distribution of magnitude is similar in all phases: most of the speed actions correspond to small speed adjustments. Indeed, as in May’02 experiment, 65% of the speed actions correspond to adjustments within -15kt and +5kt. However, large speed changes occur in any of the three phases.

![Figure 58: Distribution of speed magnitude (LFPO scenario). “Acquisition” phase.](image1)

![Figure 59: Distribution of speed magnitude (LFPO scenario). “Maintaining” phase.](image2)

![Figure 60: Distribution of speed magnitude (LFPO scenario). “Remaining” phase.](image3)

To address further the impact of the spacing task on pilot activity, we tested two hypotheses. First we looked for a correlation between the number of speed actions and their magnitude. We assumed that performing larger speed variations could induce less frequent speed changes. No clear trend emerged from the results (Figure 61).
Second we looked for a correlation between the duration of the “acquisition” phase and the number of speed actions performed during the “merge” phase. We assumed that smaller “acquisition” phase would lead to more numerous speed actions during the “merge” phase. No clear trend emerged from the results (Figure 62). It shall be reminded that in the LFPG scenario, the spacing was almost reached at the beginning of the run, which induced a very short acquisition period. However, when comparing LFPO and LFPG, no clear difference can be identified. The different length of the respective acquisition period does not induce difference in the average number of speed actions per minute.

**Synthesis on spacing tasks:** As in May'02, the analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is less than 1.5 per minute, with fewer speed actions for larger tolerances (respectively 1.7, 1.3 and 1 per minute). However, the impact of tolerance is less important than expected, which may be explained by the “keep the bug aligned” culture. There are fewer speed actions in the “acquisition” phase than in the “maintain” one. In the “acquisition” phase, speed actions mainly result from acquiring the desired spacing, whereas in the “maintain” phase, speed actions are mainly triggered by changes on target state. The frequency of the speed actions could be split into two categories: less than 3 minutes (actions mainly linked to changes on target state) and between 6 and 7 minutes. In terms of magnitude, 65% of speed actions correspond to small speed adjustments (between -15kt and +5kt). No correlation was found between magnitude and number of speed actions, or between duration of “acquisition” phase and number of speed actions. The analysis of speed actions confirms results from May'02. In addition, it shows the impact of spacing tolerance on speed actions – smaller tolerance being more demanding.
5.8.4.2. Monitor and analyse traffic situation

5.8.4.2.1. Collecting information (eye tracking)

Preliminary note: the eye movement analysis conducted during the experiment was mainly investigating the technical feasibility and the relevance of the technique for the validation of the concept. It should be seen as a first step to identify potential indicators and issues. Consequently, in the present section we present some data analysis to illustrate what could be inferred from eye movement analysis. However, because the sample were very limited (1 run per condition), no interpretation of results will be proposed.

We decomposed the eye movement analysis in three main steps: macroscopic, microscopic and qualitative analysis. At each steps results should be compared between the various conditions, i.e. for the present experiment function (PF/PNF), use of spacing (with/without), tolerance margin (1/0.5/0.25NM).

**Macroscopic analysis**

The first level of analysis consists aimed at providing the characteristic of the monitoring (e.g. percentage of time, frequency) of each standard cues (e.g. speed tape, altitude tape) and new cues (e.g. target, spacing trend, spacing value, speed bug). The analysis was limited to the following flight deck elements: the ND, the PFD, the MCDU, the FCU and the ECAM.

The first step corresponds to comparing the number and duration of fixation per display unit.

**Hypothesis**: we assume that the spacing task will induce more fixations on the ND for both PF and PNF. Smaller tolerance margins are also expected to increase the number of fixations on the ND. Typical presentation of results could consist in histogram with respective number of fixation per display (Figure 63).

![Distribution of fixations per display unit. Condition with spacing, 0.5 and 0.25NM tolerance margins.](image)

As a second step, we defined for each display unit the main areas of interest. Typically, for the ND (Figure 64), we identified 9 areas of interest: (1) Spacing scale, (2) Speed, (3) Next waypoint, (4) Suggested IAS, (5) Warning messages (stabilize speed, losing spacing, unable delegation), (6) ADF-VOR1, (7) ADF-VOR2, (8) Wind and (9) Rest of the ND (which might contain the target aircraft).
Hypothesis: we assume that the spacing task will induce more fixations on the spacing scale and on the suggested IAS than on the other areas of interest on the ND for both PF and PNF. The same effect is expected from smaller margins.

The fixation analysis could investigate the respective number of fixation on each area of interest in various conditions (Figure 65). The example provided does not show differences between the two conditions. It shall be stressed that some areas of interest depend on the context: typically, the "spacing scale" (1) and the "SUG_IAS" (4) are relevant during the spacing task, whereas they should be included in the "rest of the ND" area (9) when in conventional flight phase.

Figure 65: Respective percentage of fixation on areas of interest on the ND. Condition with spacing, 0.5 and 0.25NM tolerance margins.

The same analysis could be done for each display unit. Description of areas of interest and distribution of fixations per area for the other display units are presented in the annex. For each display unit and more specifically the MCDU, the present definition of areas of interest are strictly limited to situations when spacing task is performed and specific information displayed (e.g. ASAS MCDU page opened, provision of warning message).

Distributions in the various conditions (without/with spacing; 0.25/0.5/1NM tolerance margin; PF/PNF) should be compared.
Microscopic analysis

The second level of analysis aims at relating the characteristic of the monitoring to both the context of the flight and the spacing task, e.g. using a timeline basis. We represented the temporal distribution of fixations per flight deck element. Scenario-related events are added over the temporal distribution (Figure 66). Such a presentation of information enables the changes in objects (or areas) of attention to be first of all detected and second put in relation with scenario-related events. Such an analysis is still incomplete: contextual information is still missing to understand changes in focus of fixations. Typically, on-going tasks, occurring communication in the cockpit could also provide additional information.

In the present example, we notice that target selection induces an increase in fixations on the MCDU. This can be explained by the fact that the PNF is in charge of entering target information in the MCDU in order to proceed to the target selection. During the descent phase (target and own), which induces changes in both aircraft speed, close monitoring is required in addition to speed adjustments. Whereas the PF is in charge of the speed adjustments, it is not surprising that the PNF looks more on the PFD, typically to check actions taken by the PF.

![Temporal distribution of fixations per flight deck element, including scenario-related events.](image)

For comparable scenarios, when same events occur at the same time, comparison could be made between conditions. In addition, for a same run, such an analysis could enable the comparison between PF and PNF monitoring task.

Qualitative analysis

The third level of analysis aims at understanding and identifying scanning patterns in conventional flight, and assessing any change with the new task allocation.

**Hypothesis:** we assume that even though the spacing task will modify the number of fixations on the ND, the overall scanning patterns will not be modified. In other words, in all conditions, pilots will be in a position to perform their regular scanning patterns and collect information about the current situation.

As a first step, we investigated for each flight deck elements the transitions between areas of interest. For each fixation on a given area, we analysed what other area of interest is concerned by the next fixation. Typically, a fixation on the spacing scale is followed by a fixation either on the scale (1), or on the rest of the ND (9) or on another flight deck element. It shall be reminded that area 9 does not correspond to the centre of the ND, but includes all areas, and typically where the target aircraft is displayed.
The next step could consist in investigating which areas of interest (on other flight deck elements) are concerned by outwards arrows.

![Diagram showing transition between ND areas of interest, PNF, with spacing, 0.5NM tolerance margin. Transition probabilities lower than 20% are not displayed.](image)

**Figure 67:** Transition between ND areas of interest, PNF, with spacing, 0.5NM tolerance margin. Transition probabilities lower than 20% are not displayed.

**Synthesis on eye tracker data analysis:** The eye tracker data analysis allows identifying metrics to assess the impact of the spacing task on pilots monitoring. Similarly to the ground experiments, three sets of metrics have been identified: macroscopic for the impact on the overall fixation distribution, microscopic for the impact on the monitoring of areas of interest, and qualitative for pilot scanning patterns in assessing transition between areas of interest.

### 5.8.5. Effectiveness

In the present experiment, effectiveness of the spacing instruction was assessed through the spacing accuracy measure.

During the initial “acquisition” phase, the spacing might be outside the fixed tolerance margin. Therefore, we analysed the spacing deviation during the “maintaining” and the “remaining” phase (Figure 68). As a reminder, the “maintaining” phase starts once the current spacing is within the tolerance margins. Results show that in all conditions, and in both phases the average spacing deviation is below 0.2NM. Some pilots said they were not using the tolerance margins but rather looking for the exact required spacing value, whereas other preferred using the margin in order to reduce the number of actions. Results highlight the first strategy. Average spacing deviation is always below the tolerance margin, while the standard deviation remains within the limit: in 0.25NM condition, the average maximum spacing deviation goes up to is 0.26, in 0.5NM condition it goes up to 0.52 and in 1 NM condition, it goes up to 0.58NM. Distributions per scenario are presented in the annex.
To extend the analysis, we looked at the distribution of average spacing deviation. For each flight, we computed the average spacing deviation value. Figure 69 shows the distribution of average values for each scenario. In both “maintain” and “remain” phases, the average deviation value is always below the minimum tolerance margin (0.25). When considering the distribution of maximum spacing deviation (Figure 70), differences between the two phases are observed. Whereas the maximum deviation value is usually between 0 and 0.2Nm in the “maintain” phase (in all conditions), it is rather between 0.2 and 0.3Nm in the “remain” phase for the 0.5 and 1NM conditions, with even some cases between 0.5 and 0.6NM. Only in the 0.25 condition the maximum spacing deviation is usually below 0.1NM. Results show two points: pilots seem to be using the tolerance margin, even though they succeed in remaining within a tight tolerance margin.
Synthesis on spacing accuracy: Pilots managed to maintain the spacing within tolerance margins except few cases. The average spacing deviation was usually below 0.15NM. The maximum spacing deviation was usually below the tolerance margin. Larger deviations were noticed during the "remain" phase, possibly reflecting the time needed to react to modification on target (start of descent and speed reduction to 250kt).

5.8.6. Safety

5.8.6.1. Subjective feedback

Compared to today situations, the situation awareness is better for the majority of pilots: crews feel safer, get a better understanding of the situation and feel more involved. Some think that the reduced traffic on the frequency might provide them with some availability useful in degraded situations (e.g. technical failure). With spacing instructions, the risk of errors does not increase. Errors induced by the spacing instruction are not likely to be neither frequent nor hazardous and could be quite easy to detect and recover. However, pilots evoke two main potential risks. The first one is that too much focus on the spacing task may lead to forget important flying tasks during busy approach phase or to decrease the monitoring of standard flight parameters. Because it is a long-lasting task, the second risk is to forget it, typically when a long period occurs between speed adjustments.

5.8.6.2. Loss of spacing

When outside the tolerance margins, we considered the spacing was lost. Four cases were observed in the 30 analysed runs (Table 15). Details about those cases are presented in the annex.

Table 15: Characteristics of cases of loss of spacing

<table>
<thead>
<tr>
<th>Phase</th>
<th>Tolerance</th>
<th>Duration</th>
<th>Estimated pilot reaction time</th>
<th>Max spacing value</th>
<th>Max spacing error</th>
<th>% of the tolerance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remain</td>
<td>+/-0.5NM</td>
<td>93s.</td>
<td>33s.</td>
<td>7.36NM</td>
<td>0.14NM</td>
<td>28</td>
<td>Descent mode awareness error detected too late</td>
</tr>
<tr>
<td>Acquisition</td>
<td>+/-0.25NM</td>
<td>41s.</td>
<td>20s.</td>
<td>8.32NM</td>
<td>0.07NM</td>
<td>28</td>
<td>Too late and too large deceleration (the assumption is that the briefing was requiring too much attention to the detriment of the spacing task)</td>
</tr>
<tr>
<td>Remain</td>
<td>+/-0.5NM</td>
<td>17s.</td>
<td>12s.</td>
<td>7.45NM</td>
<td>0.05NM</td>
<td>10</td>
<td>Initial suggested deceleration not followed and late use of speed brakes</td>
</tr>
<tr>
<td>Remain</td>
<td>+/-0.25NM</td>
<td>77s.</td>
<td>40s.</td>
<td>7.64</td>
<td>0.11NM</td>
<td>44</td>
<td>Reactions (deceleration and use of speed brakes) occurring too late and not intense enough.</td>
</tr>
</tbody>
</table>

5 Time between the “LOSING SPACING” message display and the closure rate reaching 0. It is an indicator of the reaction time of the pilot plus the reaction time of the aircraft.
5.8.6.3. Large speed magnitude

Cases of speed actions with magnitude greater than 30 knots were closely analysed. The objective was to understand what caused such large adjustments. 25 cases were observed in 16 out of 23 runs, corresponding to 5 out of 7 crews. 2 cases were caused by a system bug. 16 cases correspond to adjustment to target speed reduction. 1 case corresponded to a too early anticipation of the target speed reduction. 2 cases correspond to excessive speed adjustment aiming to correcting drifting situation. Similarly, 4 cases reflected correction of previous action.

Synthesis on safety: Pilot subjective feedback was rather positive. Compared to today situations, the situation awareness is better for the majority of pilots: crews feel safer, get a better understanding of the situation and feel more involved. However they said they dread either to focus too much on the spacing task during busy flight phases or to forget it when no action is needed during a long period of time. Over the 30 measured runs with spacing, 4 cases of loss of spacing (1 smaller than required, 3 larger) were observed. A detailed analysis of the context was conducted. They occurred for 0.5 and 0.25 tolerance. The spacing error was below 0.15NM, corresponding approximately to 30% of the tolerance. They were mainly due to late pilot reaction in conjunction with under or over reaction. The estimated reaction time was around 30s.

5.9. CONCLUSION

The main objective of the December’02 experiment was to assess the relation between spacing tolerance (+/-0.25NM, +/-0.5NM and +/-1NM) and flight crew activity, effectiveness and safety. A recurrent objective was to assess the usability of the improved interface. In addition, an eye tracker device was introduced to identify if and how eye movement analysis could be used to assess impact on monitoring. Seven flight crews participated during 1 day each (1½ day for “new comers”). Flight crews were tasked to acquire and maintain the spacing in a “merge” situation, from cruise to the initial approach fix. In addition, they performed a reference flight with conventional instructions.

Flight crew feedback was generally positive. As in the May’02 experiment, they highlighted the positive aspects of getting in the loop, understanding their situation (through goal-oriented instructions), and gaining anticipation despite a new task in the cockpit which requires appropriate assistance to contain workload.

Compared to May’02, the flight crew felt that the additional assistance (a spacing scale and a suggested airspeed) improved the interface. A managed spacing mode is a recurrent demand from some pilots.

In terms of effectiveness, in all experimental conditions pilots achieved a very accurate spacing. However, if tolerances of 1 and 0.5NM seem feasible to maintain under nominal conditions, the 0.25NM tolerance seems more difficult and requires more effort and attention.

The hypothesis regarding the impact of tolerance margins on flight crew activity was that smaller tolerance margins would induce higher workload, both in terms of number of actions and monitoring demand. Results showed that the smallest tolerance margin impose more monitoring. However, the impact of tolerance margins on number of speed actions was lower than anticipated. This is probably due to the “keep the bug aligned” culture.

Pilots overall feeling on safety was positive. However they identified the risk to focus too much on the spacing task during busy flight phases and the risk to forget it when no action is needed during a long period of time.

Even though the eye movement analysis was performed on a limited number of runs, it allows identifying metrics to assess the impact of the spacing task on flight crew activity. The metrics are categorised in macroscopic, microscopic and qualitative analyses.

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6 For 7 out of the 30 analysed runs, the suggested IAS was not available.
6. CONCLUSION

The purpose of this document was to present the results and findings of the CoSpace flight deck experiments conducted in May and December 2002.

The objectives of the May’02 experiment were to investigate the feasibility of three spacing instructions (“remain”, “merge” and “heading then merge”) and their impact on flight crew activity and effectiveness. The target was initially either in cruise or in descent. Going a step further, the objectives of the December’02 experiment were to assess the relation between 3 spacing tolerances (±1NM, ±0.5NM and ±0.25NM) and flight crew activity, effectiveness as well as safety with the “merge” instruction. Three dimensions were considered for validation: acceptability, pilot activity and effectiveness. The safety dimension was introduced for Dec’02.

6.1. MAY’02 EXPERIMENT

6.1.1. Acceptability

Flight crews perceived benefits introduced by the spacing task, typically the active part they take in the management of the spacing and the better understanding of the situation. Additional support to perform the spacing task, through improved interface is requested (speed advisory for manual mode and a managed mode). Despite a higher mental and temporal perceived workload for the pilot flying, the workload is described as acceptable by both pilots.

6.1.2. Pilot activity

The analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is below 1.5 per minute. No difference was found across experimental conditions (type of spacing instruction and initial flight phase of the target). Differences were higher between pilots in particular for the min and max number of speed actions. Temporal distribution of speed actions provides a contextual understanding of their occurrence. In most cases, and in all experimental conditions, speed actions are triggered by modification on target (start of descent and speed reduction to 250kt). In terms of magnitude, 65% of speed actions correspond to rather small adjustments (between -15kt and +5kt).

6.1.3. Effectiveness

Despite the basic assistance and the manual mode, pilots could in all conditions maintain the required spacing within tolerance margin (±1NM). Results suggest two strategies: aiming at the exact required spacing value or aiming at staying within the tolerance margin. No correlation between these two strategies and their respective cost in terms of speed actions could be found.
6.2. DEC’02 EXPERIMENT

6.2.1. Acceptability

The overall feedback was positive. Modification on the interface improved its usability. The increased workload with the spacing instruction is considered as acceptable. However the smallest tolerance margin (+/-0.25NM) induced higher perceived workload, especially for the pilot flying and was perceived as more demanding in terms of monitoring. Despite interface improvements, some pilots asked for a managed mode.

6.2.2. Pilot activity

As in May’02, the analysis of pilot activity focused on the manual speed actions required to perform the spacing task. The average number of speed actions is less than 1.5 per minute, with fewer speed actions for larger tolerances (respectively 1.7, 1.3 and 1 per minute). However, the impact of tolerance is less important than expected, which may be explained by the “keep the bug aligned” culture. There are fewer speed actions in the “acquisition” phase than in the “maintain” one. In the “acquisition” phase, speed actions mainly result from acquiring the desired spacing, whereas in the “maintain” phase, speed actions are mainly triggered by changes on target state. The frequency of the speed actions could be split into two categories: less than 3 minutes (actions mainly linked to changes on target state) and between 6 and 7 minutes. In terms of magnitude, 65% of speed actions correspond to small speed adjustments (between -15kt and +5kt). No correlation was found between magnitude and number of speed actions, or between duration of “acquisition” phase and number of speed actions. The analysis of speed actions confirms results from May’02. In addition, it shows the impact of spacing tolerance on speed actions – smaller tolerance being more demanding.

The eye tracker data analysis allows identifying metrics to assess the impact of the spacing task on pilots monitoring. Similarly to the ground experiments, three sets of metrics have been identified: macroscopic for the impact on the overall fixation distribution, microscopic for the impact on the monitoring of areas of interest, and qualitative for pilot scanning patterns in assessing transition between areas of interest.

6.2.3. Effectiveness

Pilots managed to maintain the spacing within tolerance margins except few cases discussed in the report. The average spacing deviation was usually below 0.15NM. The maximum spacing deviation was usually below the margin tolerance. Larger deviations were noticed during the “remain” phase, possibly reflecting the time needed to react to modification on target (start of descent and speed reduction to 250kt).

6.2.4. Safety

Pilot subjective feedback was rather positive. Compared to today situations, the situation awareness is better for the majority of pilots: crews feel safer, get a better understanding of the situation and feel more involved. However they said they dread either to focus too much on the spacing task during busy flight phases or to forget it when no action is needed during a long period of time.
Over the 30 measured runs with spacing, 4 cases of loss of spacing (1 smaller than required, 3 larger) were observed. A detailed analysis of the context was conducted. They occurred for 0.5 and 0.25 tolerance. The spacing error was below 0.15NM, corresponding approximately to 30% of the tolerance. They were mainly due to late pilot reaction in conjunction with under or over reaction. The estimated reaction time was around 30s.

6.3. NEXT STEPS

The main objective of the next air experiment in mid 2003 will be to assess the feasibility of time-based airborne spacing until the final approach phase. The assessment will rely on the same methodology but the validation model will be updated (adapted) so as to match the last version of the validation model designed for controller experiments (CoSpace 2003). Scenarios will be based on the findings from the controller approach experiment conducted in November 2002.
Ce rapport présente les résultats des expérimentations bord conduites en mai et décembre 2002 dans le cadre du projet CoSpace. Ces expérimentations s’insèrent dans une série d’exercices de validation, sol et bord, visant à étudier l’utilisation d’instructions d’espace ment pour le séquencement des flux d’arrivées. La faisabilité des tâches d’espace ment a été évaluée lors de l’expérimentation précédente conduite en novembre 2000, principalement à travers l’utilisabilité de l’interface homme-machine. Pour aller plus loin, les présentes expérimentations visent à évaluer la faisabilité de ces tâches ainsi que leurs impacts sur l’activité des pilotes et l’efficacité. L’étude s’étend de la phase de croisière à l’approche initiale avec des instructions d’espace ment en distance et un avion cible sous contrôle conventionnel. Alors qu’en mai trois instructions d’espace ment ont été considérées, seule une instruction a été utilisée en décembre afin de tester trois tolérances d’espace ment.

L’expérimentation de mai 2002

Les objectifs de cette expérimentation étaient d’étudier la faisabilité de trois instructions d’espace ment (“remain”, “merge” et “heading then merge”) et leurs impacts sur l’activité des pilotes et l’efficacité.

Cinq équipages (deux pilotes d’essai et huit pilotes de ligne) ont participé à cette expérimentation, une journée chacun. Les vols consistaient en des arrivées sur Paris Orly. L’équipage avait pour consigne de réaliser la tâche d’espace ment avec des ajustements de vitesse manuels en plus de leurs tâches de vol conventionnelles sur un simulateur de cockpit.

L’introduction de la tâche d’espace ment a été perçue de façon positive par les pilotes, notamment parce qu’ils prennent une part active à la gestion de l’espace ment et ont une meilleure compréhension de la situation. Ils ont exprimé le souhait d’avoir des aides supplémentaires à travers l’amélioration de l’interfaces homme-machine (une vitesse suggérée en mode manuel voire un mode managé). En dépit de la perception d’une charge de travail mentale et temporelle plus importante pour le pilote en fonction, les deux pilotes décrivent la charge de travail comme acceptable.

L’analyse de l’activité des pilotes s’est focalisée sur les actions de vitesse manuelles requises pour réaliser la tâche d’espace ment. Le nombre moyen d’actions de vitesse est inférieur à 1.5 par minute. Aucune différence n’a été observée en fonction des conditions expérimentales (type d’instruction d’espace ment et phase de vol initiale de la cible). En termes d’amplitude, 65% des actions de vitesse correspondent à de petits ajustements (entre -15kt et +5kt). En dépit d’une assistance réduite et du mode manuel, les pilotes ont pu maintenir l’espace ment requis dans la marge de tolérance (+/-1NM) dans toutes les conditions.

L’expérimentation de décembre 2002

Les objectifs de cette expérimentation étaient d’étudier, pour l’instruction de “merge”, la relation entre trois tolérances d’espace ment (+/-1NM, +/-0.5NM et +/-0.25NM) et l’activité des pilotes, l’efficacité et la sécurité.

Comme en mai 2002, le retour des pilotes était positif. L’augmentation de la charge de travail induite par l’instruction d’espacement est considérée comme acceptable. Toutefois, la plus petite marge de tolérance (+/-0.25NM) induit une charge de travail perçue plus importante, surtout pour le pilote en fonction. Elle est aussi perçue comme plus exigeante du point de vue de la surveillance (“monitoring”). Les modifications apportées à l’interface homme-machine ont amélioré l’utilisabilité du système. Néanmoins, certains pilotes demandent toujours un mode managé.

Comme en mai 2002, l’analyse de l’activité des pilotes s’est focalisée sur les actions de vitesse manuelles requises pour réaliser la tâche d’espacement. Le nombre moyen d’actions de vitesse est inférieur à 1.5 par minute avec une diminution du nombre d’actions pour les tolérances plus grandes (respectivement, 1.7, 1.3 et 1 par minute). Toutefois, l’impact de la tolérance est moins important que prévu ; cela peut s’expliquer par la culture “aligner les barres". La fréquence des actions de vitesse peut être séparée en deux catégories: moins de 3 minutes (actions liées principalement aux changements d’état de l’avion cible) et entre 6 et 7 minutes. En termes d’amplitude, 65% des actions correspondent à de petits ajustements (entre -15kt et +5kt).

L’analyse des données issues du dispositif de suivi du regard (“eye tracking”) a permis d’identifier des métriques pour évaluer l’impact de la tâche d’espacement sur la surveillance (“monitoring”) effectuée par les pilotes. De même que pour les expérimentations sol, trois ensembles de métriques ont été identifiés : macroscopique pour l’impact sur la distribution globale des fixations, microscopique pour l’impact sur le contrôle des zones d’intérêt et qualitative pour les parcours visuels en évaluant les transitions entre zones d’intérêt.

Les pilotes ont réussi à maintenir l’espacement dans les marges de tolérance à quelques exceptions discutées dans le rapport. L’écart d’espacement moyen était généralement inférieur à 0.15NM. L’écart d’espacement maximum était généralement inférieur à la marge de tolérance.

Concernant la sécurité, le retour des pilotes était plutôt positif. Par rapport à aujourd’hui, la représentation mentale de la situation est meilleure pour la majorité des pilotes : les équipages se sentent plus en sécurité, ont une meilleure compréhension de la situation et se sentent plus impliqués. Néanmoins, ils craignent, soit de trop se focaliser sur la tâche d’espacement pendant les phases de vol chargées, soit de l’oublier lorsqu’elle ne nécessite aucune action pendant de longues périodes.

Conclusion

Ces expérimentations ont permis d’avoir une compréhension globale de l’impact de l’espacement sur l’activité des pilotes ainsi que sur l’efficacité en croisière et en descente. La nouvelle tâche d’espacement a été réalisée avec succès et s’intègre bien dans l’activité en vol.

L’objectif principal de la prochaine expérimentation bord mi 2003 sera d’évaluer la faisabilité de l’espacement en temps et d’étendre l’analyse jusqu’à la phase d’approche finale. L’évaluation reposera sur la même méthodologie, mais le modèle de validation sera mis à jour pour être cohérent avec la dernière version utilisée dans les expérimentations sol.
1. INTRODUCTION


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 l’expérimentation conduite en mai 2002.
- La section 5 décrit l’expérimentation conduite en décembre 2002.
- La section 6 présente les conclusions et définit les étapes suivantes.

2. OBJECTIFS


3. CONCLUSION

Ce rapport présente les résultats des expérimentations bord conduites en mai et décembre 2002 dans le cadre du projet CoSpace.

Les objectifs de l’expérimentation de mai 2002 étaient d’étudier la faisabilité de trois instructions d’espacement (“remain”, “merge” et “heading then merge”) et leurs impacts sur l’activité des pilotes et l’efficacité. L’avion cible était initialement en croisière ou en descente. Pour aller plus loin, les objectifs de l’expérimentation de décembre 2002 étaient d’étudier, pour l’instruction de “merge”, la relation entre trois tolérances d’espacement (+/-1NM, +/-0.5NM et +/-0.25NM) et l’activité des pilotes, l’efficacité et la sécurité. Trois dimensions ont été considérées pour la validation : acceptabilité, activité des pilotes et efficacité. La dimension sécurité a été introduite en décembre 2002.
3.1. **L’EXPERIMENTATION DE MAI 2002**

3.1.1. **Acceptabilité**

L’introduction de la tâche d’espacement a été perçue de façon positive par les pilotes, notamment parce qu’ils prennent une part active à la gestion de l’espacement et ont une meilleure compréhension de la situation. Ils ont exprimé le souhait d’avoir des aides supplémentaires à travers l’amélioration de l’interface homme-machine (une vitesse suggérée en mode manuel voire un mode managé). En dépit de la perception d’une charge de travail mentale et temporelle plus importante pour le pilote en fonction, les deux pilotes décrivent la charge de travail comme acceptable.

3.1.2. **Activité des pilotes**

L’analyse de l’activité des pilotes s’est focalisée sur les actions de vitesse manuelles requises pour réaliser la tâche d’espacement. Le nombre moyen d’actions de vitesse est inférieur à 1.5 par minute. Aucune différence n’a été observée en fonction des conditions expérimentales (type d’instruction d’espacement et phase de vol initiale de la cible). Les différences étaient notables entre pilotes, particulièrement pour le nombre minimum et maximum d’actions de vitesse. La distribution temporelle des actions permet la compréhension de leur contexte d’occurrence. Dans la plupart des cas et dans toutes les conditions expérimentales, les actions de vitesse sont déclenchées par des modifications d’état de l’avion cible (début de descente et réduction de vitesse à 250kt). En termes d’amplitude, 65% des actions de vitesse correspondent à de petits ajustements (entre -15kt et +5kt).

3.1.3. **Efficacité**

En dépit d’une assistance réduite et du mode manuel, les pilotes ont pu maintenir l’espacement requis dans la marge de tolérance (+/-1NM) dans toutes les conditions. Les résultats suggèrent deux stratégies : viser la valeur d’espacement exacte ou essayer de rester dans la marge de tolérance. Aucune corrélation entre ces deux stratégies et leur coût respectif en termes d’actions de vitesse n’a pu être montrée.

3.2. **L’EXPERIMENTATION DE DECEMBRE 2002**

3.2.1. **Acceptabilité**

Le retour général des pilotes fut positif. L’utilisabilité du système a été améliorée par les modifications apportées à l’interface homme-machine. L’augmentation de la charge de travail induite par l’instruction d’espacement est considérée comme acceptable. Toutefois, la plus petite marge de tolérance (+/-0.25NM) induit une charge de travail perçue plus importante, surtout pour le pilote en fonction. Elle est aussi perçue comme plus exigeante du point de vue de la surveillance (“monitoring”). En dépit des améliorations de l’interface, certains pilotes demandent toujours un mode managé.
3.2.2. Activité des pilotes

Comme en mai 2002, l’analyse de l’activité des pilotes s’est focalisée sur les actions de vitesse manuelles requises pour réaliser la tâche d’espacement. Le nombre moyen d’actions de vitesse est inférieur à 1.5 par minute avec une diminution du nombre d’actions pour les tolérances plus grandes (respectivement, 1.7, 1.3 et 1 par minute). Toutefois, l’impact de la tolérance est moins important que prévu ; cela peut s’expliquer par la culture “aligner les barres”. La phase d’“acquisition” comprend moins d’actions de vitesse que la phase de “maintain”. Dans la phase d’“acquisition”, les actions de vitesse résultent de l’acquisition de l’espacement requis alors que dans la phase de “maintain”, les actions de vitesse sont principalement déclenchées par les changements d’états de l’avion cible. La fréquence des actions de vitesse peut être séparée en deux catégories : moins de 3 minutes (actions liées principalement aux changements d’état de l’avion cible) et entre 6 et 7 minutes. En termes d’amplitude, 65% des actions correspondent à de petits ajustements (entre -15kt et +5kt). Aucune corrélation n’a pu être montrée entre l’amplitude et le nombre d’actions ou entre la durée de la phase d’“acquisition” et le nombre d’actions de vitesse. L’analyse des actions de vitesse confirme les résultats obtenus en mai 2002. De plus, elle montre l’impact de la tolérance d’espacement sur les actions de vitesse – les tolérances les plus petites sont les plus exigeantes.

L’analyse des données issues du dispositif de suivi du regard (“eye tracking”) a permis d’identifier des métriques pour évaluer l’impact de la tâche d’espacement sur la supervision effectuée par les pilotes. De même que pour les expérimentations sol, trois ensembles de métriques ont été identifiés : macroscopique pour l’impact sur la distribution globale des fixations, microscopique pour l’impact sur le contrôle des zones d’intérêt et qualitative pour les parcours visuels en évaluant les transitions entre zones d’intérêt.

3.2.3. Efficacité

Les pilotes ont réussi à maintenir l’espacement dans les marges de tolérance à quelques exceptions discutées dans le rapport. L’écart d’espacement moyen était généralement inférieur à 0.15NM. L’écart d’espacement maximum était généralement inférieur à la marge de tolérance. Des écarts plus importants ont été notés pendant la phase de “remain”, reflétant peut-être le temps nécessaire pour réagir aux changement d’état de l’avion cible (début de descente et réduction de vitesse à 250kt).

3.2.4. Sécurité

Le retour des pilotes était plutôt positif. Par rapport à aujourd’hui, la représentation mentale de la situation est meilleure pour la majorité des pilotes : les équipages se sentent plus en sécurité, ont une meilleure compréhension de la situation et se sentent plus impliqués. Néanmoins, ils craignent, soit de trop se focaliser sur la tâche d’espacement pendant les phases de vol chargées, soit de l’oublier lorsqu’elle ne nécessite aucune action pendant de longues périodes.

Sur les 30 exercices mesurés avec instruction d’espacement, 4 cas de perte d’espacement ont été observés (1 inférieur à la valeur requise et 3 supérieurs). Une analyse détaillée du contexte a été réalisée. Les pertes d’espacement se sont produites pour des tolérances de 0.5NM et 0.25NM. L’erreur d’espacement est inférieure à 0.15NM, ce qui correspond approximativement à 30% de la tolérance. La cause principale fut la réaction tardive du pilote couplée à une sous ou sur réaction. Le temps de réaction estimé était aux alentours de 30s.
3.3. FUTURE EXPERIMENTATION