INTRODUCING A NEW SPACING INSTRUCTION. IMPACT OF SPACING TOLERANCE ON FLIGHT CREW ACTIVITY

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To assess, from flight crew perspectives, the benefits and limits of a new spacing instruction, a pilot-in-the-loop experiment was conducted. Beyond assessing interface usability and overall feasibility, the experiment aimed at analysing the impact of various tolerance margins on flight crew activity. Flight crew feedback was generally positive. Despite a new task in the cockpit, which requires appropriate assistance to contain workload, pilots highlighted the positive aspects of getting in the loop, understanding their situation, and gaining anticipation. Results showed that the average spacing deviation was usually below 0.5NM.

INTRODUCTION

In the context of continuous traffic increase, various approaches investigated a possible task re-allocation between controllers and flight crews. Whereas free flight paradigm showed limitations in terms of controller role and involvement (Corker, 1999; Dekker & Woods, 1999), more conservative approaches seemed promising (Casaux & Hasquenoph, 1997; Johnson et al., 1999; Zeitlin et al., 1998). The key driver of the present study is to increase controller availability through a reorganisation of tasks between controller and flight crew. 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. The proposed task allocation relies on the use of a new spacing instruction, which requires the flight crew to implement a solution defined by the controller. Typically, for sequencing applications in terminal areas, the flight crew is tasked to adjust speed to maintain a desired spacing. Restricting the situation to implementation tasks (as opposed to decision making tasks) is expected to preserve controller authority and understanding of the situation. The use of spacing instruction is at controller initiative, who can decide to end it at any time. The flight crew however can only abort it in case of problem onboard such as a technical failure. The instruction applies to pair-wise situations: one aircraft is “spacing instructed”, the other being “target”. In terms of responsibility, the spacing instruction is nothing more than a new instruction. Thus, the controller is responsible to issue the appropriate instruction to guarantee the spacing (and the separation), and the flight crew is responsible to follow it. It is expected that the increased controller availability could lead to improved safety, which in turn could enable better efficiency and/or, depending on airspace constraint, 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 the situation with respect to the concerned aircraft.

A series of 4 controller-in-the-loop experiments, involving a total 23 European controllers were conducted between 1999 and 2001 to assess the impact of the spacing instruction from controller perspective. The feedback was positive: the instruction is perceived as useful and potentially leading to more anticipation and to an overall workload reduction. Results show an overall reduction of manoeuvring instructions. In addition, eye movement analysis suggests that, even with very high traffic, controllers can still anticipate the sequencing of the arrival streams (Rognin et al., 2002). Similarly, an initial assessment of feasibility was conducted in a simplified environment consisting of a fixed base cockpit simulator with limited assistance to the flight crew to perform the spacing task (Hoffman et al., 2002). Even though the focus was more on interface usability, a number of human factor issues has been identified, stressing expected benefits and possible limits in terms of workload, function allocation and safety. In order to go a step beyond and assess the impact of the spacing task on flight crew activity, a new pilot-in-the-loop experiment took place in December 2002. The experimental design took advantage of previous controller-in-the-loop experiments, and in particular its
operational context and its validation framework. This paper aims at presenting some results obtained. It is composed of four sections: background, experiment objectives, experiment set-up, and results.

**METHOD**

**Apparatus**

Seven crews, currently flying for European airlines and all qualified on Airbus A320 aircraft, took part in the experiment. The fixed base cockpit simulator is an Airbus A320 FMGS trainers (from FAROS) allowing automatic flight, with captain and first officer positions. 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 ECAM. No external view is available. 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 situation involving the target aircraft. The main visualisation items are a suggested speed and a spacing scale indicating current and required spacing, spacing trend, closure rate and tolerance margins (Figure 1).

**Experiment design**

The experiment objectives led to a 3×2 design: spacing tolerance margin (±1, 0.5, 0.25NM) × function (flying, not flying pilot). Each pilot flew 3 times as PF and 3 times as PNF. In addition, for baseline purpose, each pilot flew once as PF without spacing instruction.

Objective data consisted of system recordings, including aircraft parameters, pilots’ actions, spacing parameters (e.g. spacing value). Subjective data consisted of observations, questionnaires and debriefing items. To support the data analysis, we derived indicators and metrics previously defined for controllers. Four dimensions were assessed: the concept acceptability, its impact on activity, on efficiency and on safety. Low level measures were identified to inform each metric (Table 1).

**Procedure**

The participants were given detailed briefing on the spacing procedure and on the new cockpit interface elements. Then, training sessions enabled them to become familiar with the simulator and with the interfaces. Flights consisted of arrivals to Paris Orly and Charles De Gaulle from cruise to initial approach, and lasted about 20 minutes. 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. 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 converging situation, through manual speed adjustments with the support of display cues. The target aircraft was under conventional control.
## RESULTS

### Usability

Whereas the MCDU is essential during the target selection phase, back-up information displayed during the spacing task are actually not perceived as useful by pilots. The 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 pilots. The suggestion of a speed seems to reduce the number of actions required. However, more support is still required to detect changes in the target behaviour.

### Workload

With the spacing task, pilots rated the communication load as lower at both PF and PNF positions: communications with controllers are less frequent and shorter, whereas communications in the cockpit are more frequent or same as today, but shorter. NASA-TLX scores show that the spacing task induces an increase in the overall mental demand for both PF and PNF: scores evolve from 22 to 40 for both of them. The impact of tolerance margin is only noticeable on the PF workload: reducing margin leads to increasing mental demand from 40 with 1NM margin to 52 with 0.25NM margin (Figure 2).

The tolerance 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 tolerance margin may lead to more adjustments, it seems consistent that the PF workload is perceived higher with smaller tolerance margin. With 1 and 0.5NM margins, workload remains acceptable as it is far from "effortful". However with 0.25NM margin, it gets closer to "rather effortful". Similarly, compared to conventional flight, the spacing task induces a small increase in temporal demand for both pilots: temporal load evolves from 3.5 to 5 on the 10 levels scale. However, it gets even higher for the PF with smaller tolerance margins, increasing up to 7.8. This could be related to the tighter monitoring and speed adjustments required to remain within acceptable limits. Whereas the demand seems acceptable with 1 and 0.5 margins, the 0.25NM margin is not.

### Spacing task

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 between current and required spacing values, (2) look at current spacing, at trend and at suggested speed, (3) compare with own speed (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 pilots activity, flight phases and events are considered. During the simulation runs, aircraft evolve from cruise to initial approach fix. Three flight phases were identified: cruise, initial descent (from the top of descent until exit level) and initial approach. Events marking these phases are descent instruction (e.g. "descend flight level 100") and target speed reduction when it is reaching the required flight level. Considering the spacing task, three phases can be distinguished: identifying the target, acquiring the spacing (between spacing instruction and passing waypoint) and maintaining the spacing behind the target.

During the runs different strategies were observed: typically some pilots tried to acquire the spacing as soon as possible, whereas other followed the constraint, that was to acquire it at a given point. This leads to define three analysis periods during the spacing task: initial

![Figure 2. NASA-TLX scores. Mental demand.](image)

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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, too much time is spent monitoring the spacing especially when the target reduces its speed.
acquisition (between instruction and reaching of the required spacing value +/- the tolerance margin), spacing maintaining until target passes merging point, spacing maintaining once target has passed the waypoint. To avoid confusion, the last phase is called “remaining behind”. When analysing the average number of speed adjustments per minute in each phase (Figure 3), two points were noticed: the remaining phase demands the most frequent 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 adjustments.

To relate speed actions to flight phases, their temporal distribution was looked at (Figure 4). The distribution shows that speed actions are triggered by target events (descent followed by speed restriction at exit point). The tolerance margins do not modify the shape of the temporal distribution, but they modify the number of actions per minute: smaller margins lead to more numerous actions than larger margin.

The acquisition phase is the least demanding in terms of number of actions, especially with 0.5 and 1NM tolerance margins. Acquiring the spacing usually requires 1 speed action, while maintaining in spite of target events required many more actions. Beyond their number, the magnitude of speed actions was analysed. Average figures show that 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 regularly performing 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 large changes might amplified knock-on effect. However, too frequent speed adjustments might induce too much focus on the spacing task.

Spacing accuracy

To assess the effectiveness of the spacing task, we considered how accurately the spacing could be maintained. During the initial acquisition phase, the spacing is initially outside the fixed tolerance margin. It seemed appropriate to restrict the analysis of the spacing deviation during the maintaining and the remaining phase (Figure 6). 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 0.25NM. Some pilots said they were not using the tolerance margins but
rather looking for the exact required spacing value, whereas others preferred using the margin in order to reduce the number of actions. Results highlight the second strategy.

To extend the analysis, the distribution of average spacing deviation was looked at (Figure 7). In both maintain and remain phases, the average deviation value corresponds to the tolerance value: with 0.25NM margin, average values are between 0 and 0.1NM, with 0.5NM between 0 and 0.2NM and with 1NM margin between 0.1 and 0.4NM. Results show that even though pilots look for the exact spacing value, they do remain within a tight tolerance margin.

![Figure 7. Distribution of average spacing deviation.](image)

**Safety**

Compared to today situations, the situation awareness is felt 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 risks of omission with this long lasting task.

**CONCLUSION**

A new spacing instruction is envisaged as an option to increase controller availability. In addition to controller-in-the-loop experiments, a pilot-in-the-loop experiment was recently conducted. Beyond assessing interface usability and overall feasibility, the experiment aimed at analysing the impact of various tolerance margins on flight crew activity. Flight crews were tasked to perform a spacing task (in distance) from cruise to initial approach fix. Flight crew feedback was generally positive. Despite a new task in the cockpit, which requires appropriate assistance to contain workload, pilots highlighted the positive aspects of getting in the loop, understanding their situation (through goal-oriented instructions), and gaining anticipation. Results showed that even though the smallest margin (0.25NM) led to increased workload, the average spacing deviation was usually below 0.5NM. In terms of safety, two main risks are evoked by pilots: the spacing task might induce excessive focus on one display, and lead to a tunnelling effect. In addition, this long lasting task might be omitted, typically in case trouble-shooting tasks occur. The next step will consist in assessing the impact of the spacing task on flight crew activity in the approach flight phase, which is expected to be more demanding.

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**REFERENCE**


