FOCUS: An Intelligent Startle Management Assistant for Maximizing Pilot Resilience

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Abstract: On the flight deck, the startle effect is triggered by sudden, unexpected and possibly threatening events such as bird strikes or system failures. It is a very rapid protective and defensive reaction that can lead to a partial or total incapacitation of pilots with tragic consequences. With Single Pilot and Reduced Crew operations likely being implemented in the future, the single pilot will be forced to face and handle the startle effect alone in the cockpit. We designed and developed FOCUS (Flight Operational Companion for Unexpected Situations), an intelligent assistant designed to help single pilots overcome the startle effect. FOCUS supports pilots in regulating their stress and maintaining an adequate situational awareness. The assistant guides them to breathe at a specific pace thanks to ambient light brightness variation of the cockpit and draws their attention towards potentially unseen information. To test and improve its design, we evaluated FOCUS in an A320 simulator with five qualified pilots. In these trials, FOCUS was positively welcomed by pilots as they perceived it as a valuable addition to the cockpit. These evaluations will guide further iterations of FOCUS design and support the understanding of human-AI teaming in the cockpit in subsequent studies.

1 INTRODUCTION

In aviation, the term "startle effect" has been often used to designate that pilots were literally "startled" but also "surprised" upon an unexpected event occurrence. While startle designates the physiological reflex following an abrupt and intense stimulus (Koch, 1999), surprise is an emotion resulting from the discrepancy between one's perception and expectation. Surprise promotes “cognitive and motivational processes directed at a proper understanding of the unexpected event” (Horstmann, 2006). In the cockpit, a startle is almost always accompanied by surprise (e.g TCAS alerts, lightning strike). Surprise can also occur without startle and is primarily due to an unexpected aircraft position, ATC clearances, or other crewmember actions (Kochan et al., 2004). With the growing complexity of cockpits, automatisms are also a common source of surprise (Dehais et al., 2015). Startle and surprise can affect the motor (May & Rice, 1971; Vlasak, 1969) and cognitive (Thackray et al., 1983; Woodhead, 1958) capabilities of individuals. On the flight deck, it can lead to task interruptions, difficulties for reframing, or inappropriate cockpit inputs (BEA, 2012; KNKT, 2014).

Pilots’ recurrent training and, more generally, experience are the first barriers against the startle effect. In simulators, pilots become indeed familiar with many situations, preparing them to react accordingly in operations. Crew Resource Management (CRM) helps also in the startle effect consequences mitigation. It can be characterized by several crew competencies like leadership, teamwork,

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communication and decision making (ICAO, 2013). In 2016, Field et al. demonstrated that crews that handled unexpected events well were the ones that had good CRM, while poorly performing crews showed mediocre CRM. All the procedures already in place can also help anticipate unexpected situations and provide a framework of action to react without engaging extensive cognitive resources. Finally, the cockpit design plays a major role in minimizing the consequences of the startle effect. Recent studies tested new procedures to counter the startle effect. The procedures URP (EASA, 2015) and COOL (Landman et al., 2020) invite pilots to try to relax, breathe before acting precipitately, and then promote launching the cognitive process by focusing on what is perceived by the pilots before making decisions.

All these mitigation measures have helped prevent many crashes in the past, such as US Airways 1549 accident (NTSB, 2010). In this case, excellent CRM upon a bird strike saved the situation. However, these measures suffer from limitations. First, pilots cannot be trained to face all possible situations, and experiencing a situation in a simulator is not the same as in real life (Casner et al., 2013). Moreover, it is difficult to trigger startle and surprise in simulators. To this end, Burki-Cohen (2010) recommend an extremely realistic environment like Full Flight Simulators to maximize the chances of startle and surprise. However, as stated in the AF447 report (BEA, 2012), "Initial and recurrent training as delivered today does not promote and test the capacity to react to the unexpected." Finally, even if procedures are put in place to prevent and minimize the startle effect, it is very difficult for pilots to apply them correctly (Grant et al., 2018; Schroeder et al., 2014). In the future, Single Pilot and Reduced Crew Operations are likely to be implemented. While the ambition of this type of operations is to at least keep the same level of safety, the impossibility to rely on a second pilot to face the startle effect is a danger that cannot be overlook.

With the advance in artificial intelligence, new systems could be implemented to support single pilots in various tasks and situations, particularly upon unexpected events occurrence. In 1997 already, Strohal & Onken presented the concept of CAMA, a cockpit assistant for military crew. Focusing on Human-centered automation, one of its functions was to recognize pilot intents and errors. With the same objective of understanding crew mental state, the Crew Workload Manager of Dorneich et al. (2011) aims to measure objectively the workload of each crew member to warn about potential workload imbalance in civil aircraft cockpits. Klaproth et al. (2020), tried also to understand pilots' cognitive state thanks to their brain activity immediately following an auditory event. Finally, Duchevet et al. (2022) and Bejarano et al. (2022) developed the HARVIS assistant which, on one hand, supports pilots taking the go-around decision thanks to machine learning and on the other hand, helps them choose the most appropriate airport during rerouting activities.

These advancements in Artificial Intelligence and the perspectives of future single pilot operations lead us to ask ourselves if a cockpit assistant could be designed to support pilots under startle effect. The study depicted here is an attempt to answer this question. In this paper, we introduce FOCUS, our Flight Operational Companion for Unexpected Situations prototype, designed to help pilots overcome the effects of startle and surprise in the cockpit. In a first part, we detail the concept of FOCUS through its two functions: the stress regulation support and the situation awareness support. In a second part, we report the results of the qualitative evaluations of the prototype, during which five professional pilots tested the intelligent assistant in an A320 simulator on two startling and surprising scenarios.

2 INTELLIGENT ASSISTANT CONCEPT

FOCUS employs two strategies to assist pilots in overcoming the effect of startle. First, it helps pilots to regulate their stress on startle event occurrence. Directly inspired from the first step of the URP (EASA, 2015) and COOL (Landman et al., 2020) procedures, we want the assistant to guide pilots to actively relax without demanding too much cognitive resources. Second, as there is a risk of loss of situation awareness upon unexpected events occurrence, the assistant will ensure that no important information is missed by the pilot, allowing to build a good mental representation of the situation. The assistant is supposed to have a startle effect detection module, but this function has not been developed in the current state of the prototype. The automatic detection of startle and surprise would enable a dynamic task allocation between the pilot and the assistant, the later ensuring the flight parameter monitoring role.

2.1 Stress Regulation Function

The assistant helps limit the negative effects of acute stress following two methods. The first method uses a green halo visual effect on cockpit screens and a green ambient light in the cockpit to guide pilots breathing deeply. As the light intensity on the screens and in the cockpit increases, the pilot breathes in, as the light intensity decreases, the pilot breathes out (Figure 1). This procedure is based on the Heart-Focus Breathing technique that is a common step to increase cardiac coherence where each breathing cycle last for 10 seconds (McCraty & Zayas, 2014).

Figure 1: Stress regulation function cockpit integration.

The effect of deep breathing on stress has been extensively demonstrated (Perciavalle et al., 2017). Breathing can be slowed down to a constant rate to increase relaxation and reducing stress levels (Schlatter et al., 2022). However, reaching an optimal breathing pace requires self-awareness and control. Therefore, the assistant will help pilots to reach cardiac coherence, a state where the heart rate variability is better controlled, to reduce the effect of stress.

The second method to limit the effect of stress is to provide pilots with vibrotactile feedback. The pilot is equipped with a device on the wrist, which provides a simulated heartbeat through vibration every second, i.e. 60 beats per minutes, when the stress regulation support is active. It is worth noting that any wrist-worn vibrating device such as now common smart watches could be used for this type of stress regulation intervention. Research has indeed shown that constant low heart rate feedback can significantly reduce anxiety (Sun et al., 2023). Experiencing tactile feedback with a simulated heartbeat at 60 beats per minute can reduce perceived anxiety (Costa et al., 2016) and heart rate after some physical efforts (Choi & Ishii, 2020).

2.2 Situation Awareness Enhancement Function

Upon an unexpected event, an orienting response is elicited, drawing the attention towards the stimulus (Bradley, 2009). In addition, the task may be interrupted (Altmann & Trafton, 2004). As situations can be highly dynamic in the cockpit, a novel event can therefore lead to a loss of global situation awareness. To counter this, FOCUS supports pilots in their perception of the elements in the environment (SA level 1) (Endsley, 1995). When the support is active, the assistant highlights the flight parameters that need to be checked such as altitude or speed. When highlighted, the parameter is wrapped with a coloured rectangular box (Figure 2). As the pilot glances at the instrument, the highlight disappears. It is made possible by an eye tracking system that track pilot's gaze position.

There are two levels of alerts based on an estimated level of criticality. The first level is "Caution," and the second level is "Warning". These levels are represented by two distinct designs on the Primary Flight Display (PFD), Navigation Display (ND), and Engine/Warning Display (ECAM). A situation awareness score is calculated for each parameter as a function of time, importance of the parameter, and speed of parameter change. As the pilot does not look at a parameter, the score associated to it will start dropping. If the situation awareness score drops below a certain threshold, the first level of alert is activated to draw the attention of the pilot. If the drop continues, the second level is activated in following.

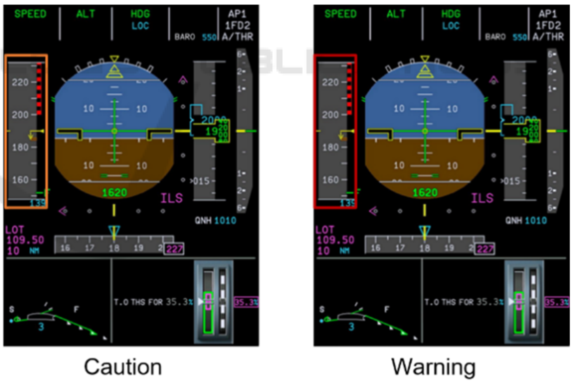

Figure 2: Situation awareness support and alert levels.

2.3 Assistant's Human-Machine Interface

On assistant start, a subliminal icon representing two humans supporting each other appears on the PFD, ND and ECAM displays for 500ms to make pilots aware of the support activation and raise the level of anthropomorphism of the assistant (de Visser et al., 2017) (Figure 3).

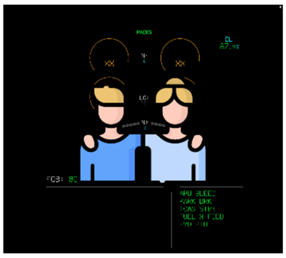

Figure 3: Assistant's icon.

The pilot can control the assistant through the Electronic Flight Bag placed on the window side of the piloting position. Each support function can be activated and disabled manually on demand, giving the pilot full control of the assistant. The pilot keeps this way the complete responsibility of the flight. The monitor also displays information which helps pilots always understand the operation of the intelligent assistant (Figure 4).

The pilot can monitor his heart rate through the assistant. This piece of information is useful to raise one's self-awareness of his own physiological state and to create an opportunity to enable stress regulation support if needed. It also allows the assistant to provide information about its functioning and an explanation for self-activation to the pilot.

The pilot can monitor the relevancy of his situation awareness. A global situation awareness score shown on the display indicates whether flight parameters reading is required. In addition, a widget mimicking the PFD suggests which areas of interest should be checked to increase the global situation awareness score. This contributes to assistant's transparency and provide opportunities to improve the pilot's situation awareness.

The interface enables pilots to cancel the automatic support execution when the intelligent assistant has identified a situation of startle. This ensures that when the assistant support is not required, the system will not interfere with the piloting tasks.

Figure 4: Assistant's HMI: stress regulation, situation awareness and auto-support monitor and control.

3 METHOD

An evaluation of the assistant prototype was conducted to collect professional pilots' feedback on the design in a realistic environment. The stress regulation and the situation awareness supports were implemented in the prototype. The startle effect detection was played in wizard of Oz.

3.1 Participants

Five pilots participated to this preliminary study (All male, mean age=43.8, SD=7.5). Four were qualified on A320 and one was qualified on Boeing aircraft (mean number of flights hours=4600, SD=5672). The protocol was approved by the ethics commission for research of the university of Toulouse (project 2023-740).

3.2 Scenarios

Two scenarios were created to evaluate the assistant: 1) a lightning strike on final approach, aiming to generate startle and surprise, 2) a shifting cargo at take-off aiming to create a surprise.

In the lightning strike scenario, the aircraft is struck by lightning on final approach. As a result, a loud bang is heard, and an intense flash is triggered, provoking startle and surprise. Because of the lightning strike, electrical problems on board of the aircraft lead to the disconnection of automatisms.

The cargo shift scenario occurs shortly after take-off. A cargo gets loose and a shift of centre of gravity occurs. As a result, a strong pitch up moment is observed, triggering a surprise. The pilot is forced to react quickly to control the aircraft and a rapid landing is necessary.

3.3 Physiological Measures

To assess if participants were startled and surprised, they were equipped with physiological sensors to monitor the cardiac (PPG, ECG), electrodermal (GSR) and muscular activity (EMG). Participants' reactions and facial expressions were filmed for ground truth.

3.4 Procedure

Upon consent form completion, each participant was first introduced to the goal and the proceedings of the study, the context and the intelligent assistant functions. The two flight scenarios of the study were then presented without disclosing the startling and surprising events (lightning strike and cargo shift). In each scenario, the flight was conducted in Single Pilot Operations. Each flying session took place in an Airbus A320 simulator.

Upon eye tracking calibration, one of the experimenters performed a walkthrough of the intelligent assistant functions and invited the participant to experience the stress regulation and the situation awareness supports. When ready, the participant began the training phase, which lasted for about 20min, aiming at familiarizing with the simulator during a take-off/landing scenario. In addition, the participant was allowed and encouraged to request support and to experience the assistant functions during the training.

After completion of the training, the participant performed the two validation scenarios in random order. At the end of the scenarios, the participant was debriefed about the experience and performance during the flight. Between each scenario, the participant filled a Likert-scale questionnaire to assess the subjective perception on the performance, the usefulness and the understanding of the intelligent assistant. Finally, when the two scenarios were completed, the participant was invited to debrief about the intelligent assistant support through a semi-structured interview in which usability, improvements, AI initiative and trust was discussed. All pilots performed the lightning strike scenario. Because of a lack of time during some evaluation sessions, only three of them performed the cargo-shift scenario in addition.

4 RESULTS

Although it is not possible to report statistics analysis given the sample size of the study, the questionnaire results and the semi-structure interviews analysis can provide experienced pilots' qualitative feedback on FOCUS.

4.1 General Feedback

The scenarios successfully triggered startle and surprise in the participants. On a scale from 1 (not startled or surprised) to 10 (very startled or surprised), participants reported an average score of 7.0 (SD=3.06) for startle and an average score of 7.6 (SD=1.51) for surprise in the lightning strike scenario. The cargo shift scenario was deemed less intense with a startle average score of 3.7 (SD=2.52) and a surprise average score of 5 (SD=2.64). Physiological data (Figure 5) and facial expressions confirmed that all the participants were startled or surprised during the lightning strike scenario. Signs of stress after the surprising event were observed in physiological data in the cargo shift scenario for all the participants. For example, P4 commented about the lightning strike scenario: "*I was sort of surprised and trying to figure out what is working and where I am, what direction am I going?*".

The assistant was generally welcomed by the participants. All of them were aware of the assistant's activation thanks to the icon appearing on screens. P4 stated that the icon disturbed his visual scan but allowed him to "take a step back". The participants thought that the assistant made them able to maintain a good situation awareness and that the awareness guidance was overall relevant. The system actions and purpose were well understood by the participants, and the assistant was thought easy to interact with. Participants felt somewhat confident to work with the assistant. That being said, the participants felt unsure about the benefits of the assistant to limit the detrimental effect of startle and surprise, and its usefulness when unexpected events occurred (i.e. in situations of surprise).

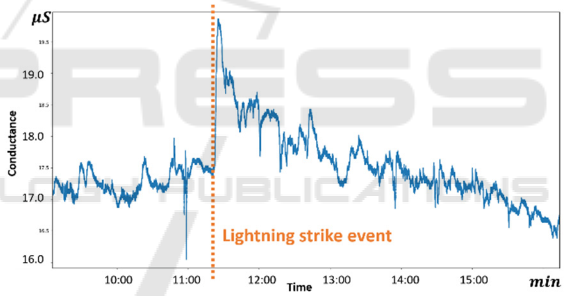

Figure 5: Example of a participant's electrodermal activity (Galvanic Skin Response) following the lightning strike event, resulting in the increase of the conductance.

4.2 Stress Regulation Support

The breathing guidance lights were seen as an indicator of stress level during the exercise (P1). By seeing the light, P4 was reminded to breathe deeply. However, participants highlighted the lack of availability to perform the breathing procedure. For instance, P2 stated: *"You need availability to focus on your cardiac rhythm"* and P3 added: *"I was thinking about it during the last [led] cycle, then I tried to adapt my breathing. Before that, I don't think I was aware of or adapting my breathing"*. Some pilots admitted that focusing on their breathing while dealing with the aircraft automation failures was quite difficult.

The tactile heartbeat simulation was not found uncomfortable. No participant noticed the tactile feedback during the exercise even though they experienced it during the training phase. Pilots were eager to know whether the tactile feedback had a real impact on their heartbeat. P2 thought that pilots could benefit from tactile feedback as it was *"transparent"* (i.e. unintrusive) to him and to other pilots, and that it did not have any impact on his workload. He added that the technology may be promising if it can be compatible with existing pilot smartwatches.

Finally, it is worth noting that none of the participants found the physiological monitoring display useful. Even though P3 was monitoring his physiological status at the beginning of the exercise, he stopped when the assistant support started. The other pilots reported that they did not look at the assistant control interface on the Electronic Flight Bag during the exercises. Pilots reported indeed that they did not have the cognitive resources to check the physiological monitoring display once the emergency declared. They had to focus on handling the emergency and controlling the aircraft.

4.3 Situation Awareness Support

The situation awareness support was useful to participants, especially when the autopilot failed in our exercise (M=3.85/5, SD=0.69). The assistant managed to draw pilots' attention towards specific parameters. P5 commented: "I missed the speed change. I was glad that the assistant told me to look at the speed". P4 thought the benefit of the situation awareness support was to "increase the sampling rate" to acquire flight information. He thought that it may have focused too long on the navigation display or on some other information. P3 said that the attention getter helped him to check the right pieces of information, even though this is what he was already planning. He reported: "I think I would have done it but it allowed me to save time". P1 also commented on the potential for such assistance to support pilot flying aircraft that they are not familiar with. With more training with the assistant, the participants thought they could follow its guidance better.

However, they also warned about the potential distraction that could result from the PFD red highlighting boxes (Warning level). Because some pilots did not look to all the instruments, more boxes started to appear on the PFD. They thought that this was overwhelming and confused them about what instrument to look first. The pilot's inability to make some boxes disappear upon glancing at it was partly due to an assistant lack of performances in recognizing Areas of Interest (AOI) in the cockpit. Particularly, it failed several times to detect the AOI associated with the heading and the localizer deviation on the Primary Flight Display resulting in constant red boxes around these zones even though pilots were looking at them.

5 DISCUSSION

Our study showed a successful cockpit integration of an intelligent assistant to support pilots during startle effect in Single Pilot Operations. As shown by participants' statements, the need to maintain a good situation awareness upon unexpected events occurrence appears to be strong and a stress regulation system seems promising. However, limits to our approach should be mentioned. As no commercial airliner is today flown single pilot, the most adequate solution for FOCUS' evaluation was to perform simulations in an Airbus A320 cockpit, even though it is not designed specifically for regular Single Pilot Operations. Moreover, the training to use the assistant was short (20 minutes) compared to standard training for new systems. With more experience with FOCUS, pilots could be more at ease with interacting with the assistant which could bring new perspectives and feedback.

Evaluating FOCUS highlighted key points for designing assistants in highly dynamic and complex situations. Even if agent transparency is vital, providing information to the pilots should not overload and disturb her/him. Thus, the availability of cognitive resources to process information appears to be one of the main challenges for startle effect management. We believe that one way to pursue our research would be to look for the most appropriate means to reduce stress in dynamic and cognitively demanding environments. Furthermore, as FOCUS adapts to pilots' behaviour thanks to the analysis of the gaze position, we could improve the situation awareness support by pushing the adaptiveness of the assistant to fit exactly pilots' profile and own scan path.

FOCUS is an attempt to design and develop a Human-Automation Teaming (HAT) agent for the cockpit. It aligns with the conceptual model of Shively et al. (2018). First, FOCUS achieves dynamic task allocation by assuming a monitoring role when a startle effect is detected. Second, bidirectional communication is present, with the pilot passively sending gaze information and physiological data, while the assistant suggests where to focus attention.

This passive communication from the pilot to the Agent might be a solution to improve team situation awareness and to communicate effectively in a dynamic situation (Demir et al., 2017), with pilots constantly pushing information without effort to the HAT agent. Finally, transparency, as with other cockpit systems, poses a challenge for FOCUS. Pilots, especially under the startle effect, have limited cognitive and time resources to comprehend the reasoning behind FOCUS outputs. Its transparency and trust in it may develop through training and post-operations analysis of agent outputs, rather than solely during operations, echoing directly a research gap depicted by Lyons et al. (2021): "What is the optimal level and method of training to team with machines [...]?". But building a solid trust in the HAT agent during training and rely exclusively on it when things go south seems dangerous. The challenge lies therefore is the following question: How to design a transparent artificial teammate while the cognitive capacities of the human counterpart are temporary diminished?

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