Bardou Maxime, Letondal Catherine, Imbert Jean-Paul, Causse Mickaël, Bidegaimberry Maxence, Dubus Romane, Marcon Cécile (2022): Redesigning systems for Single-Pilot Operations: the mutual awareness problem for remote crews. In: Proceedings of the 20th European Conference on Computer-Supported Cooperative Work: The International Venue on Practice-centred Computing on the Design of Cooperation Technologies - Exploratory Papers, Reports of the European Society for Socially Embedded Technologies (ISSN 2510-2591), DOI: 10.48340/ecscw2022_ep03

Redesigning systems for Single-Pilot Operations: the mutual awareness problem for remote crews

Bardou Maxime, Letondal Catherine, Imbert Jean-Paul, Causse Mickaël, Bidegaimberry Maxence, Dubus Romane, Marcon Cécile
Interactive Informatics, University of Toulouse - ENAC, Toulouse, France
Contact Author: maxime.bardou@enac.fr, catherine.letondal@enac.fr, jean-paul.imbert@enac.fr, mickael.causse@isae.fr

Abstract. Currently, flight safety is ensured by the collaboration of at least two pilots in the cockpit. Thanks to progress in automation and telecommunication, aircraft manufacturers and aviation companies envision that a single pilot in the cockpit assisted by a pilot on the ground (i.e Single-Pilot Operation) could ensure flight operations while requiring less human resources. However, without appropriate collaboration tools, this situation of remote collaboration may lead to a degradation of the awareness of actions and attitudes between the two pilots (i.e. mutual awareness). In this paper, we propose to enrich the understanding of the remote collaboration problems of two pilots through a fine-grained analysis of mutual awareness needs. First, we describe awareness frameworks from the literature. Second, we identify awareness issues during a case study involving a crew of pilots in two distant flight simulators. Third, we refine the relevant awareness concepts through exploratory prototyping of collaborative tools. These prototypes are based on three scenarios involving specific awareness requirements including 1) visualizing the physiological state of the pilot on board during a non stabilized approach, 2) an emergency decision making, and 3) global awareness during a whole flight for a better efficiency of the ground assistant operator at the arrival. In this article our contribution is a refined study of the awareness needs adapted to the context of remote collaborative piloting, with the final objective of designing more appropriate tools.

1 Introduction

In the coming years, the pilot's task will evolve with the arrival of a new, more automated single-pilot cockpit (Council et al., 2014). The emergence of Single-Pilot Operation (SiPO) bring new operational issues for aviation safety. To make this concept as safe as the two-pilot configuration, several scenarios are foreseen. One of them is the assistance of the pilot on board the cockpit by a ground pilot. However, this remote collaboration between on-board and ground pilot generates new problems such as the loss of awareness of the other pilot's actions and attitudes, namely the mutual awareness. The concept of SiPO is not just a question of separation between the pilot and co-pilot. This new concept leads to a modification in their collaboration with new tasks, new tools and new automatisms. Tools have already been proposed by different authors (Lachter et al., 2017) to overcome the distance issue. However, the problem would need to be better conceptualized to ensure that the tools are well fitted with remote collaboration.

Concepts of remote collaboration tools to support awareness between collaborators are already widely studied in the Computer-Supported Cooperative Work (CSCW) literature (e.g. (Beaudouin-Lafon and Karsenty, 1992; Gross, 2013; Greenberg and Gutwin, 2016; Schmidt, 2002)). Nevertheless, awareness needs between a pilot and a ground pilot during remote collaboration are not yet explicit. This article aims to answer several questions : what awareness framework are applicable in a new aeronautical context? What are the awareness needs in remote collaboration in a Single-Pilot operation context? And finally how awareness can be integrated into future collaborations tools?

To answer these questions, we will set the context, explore the challenges and hypothetical solutions to the concept of SiPO existing in the literature. In addition, we use the Antunes et al. (2014) concept of awareness and the mutual awareness concept of Schmidt (1998) in the context of the piloting activity and explore the concepts associated with collaboration tasks, which are coordination, communication and cooperation. To support our research, we also present the results from interviews that we conducted with three pairs of pilots in situations of remote collaboration in flight simulators (section 5). Finally, we describe how exploratory prototyping helped us to refine concepts of awareness in SiPO context (section 6). This exploration enabled to reflect on design in three scenarios involving specific needs of awareness. We identified a need for the ground assistant to visualize the physiological state of the pilot on board during a non stabilized approach. Then, we explored shared map for an emergency involving a rerouting. Finally, we studied how to improve the global awareness during a flight for a better efficiency of the ground assistant operator at the arrival. We conclude this paper by a discussion of our contribution and of future works.

2 Context

In the 1950s, the flight deck was composed of five members, the pilot, the co-pilot, the radio operator, the navigator, and the mechanic (Bohn, 2010). In the 1980s, the evolution of technology and the development of new on-board systems allowed the size of the crew to be drastically reduced from five to two members (pilot and co-pilot). This technological and operational evolution required new tools, new cockpit concepts (e.g., glass cockpit), as well as new safety procedure such as the Crew Resource Management (CRM) (a set of procedures to train the crew to reduce human errors). Currently, airlines companies are looking to reduce the number of crew member in a cockpit to reduce their costs. To make this possible, several scenarios are foreseen.

Over the past decade, a new phase of crew reduction in commercial aviation began to be studied by the aeronautical industry. This new phase includes two successive concepts of operations. Firstly, the extended Minimum Crew Operation (eMCO) or Reduced Crew Operation (RCO). And secondly, the Single-Pilot Operation (SiPO). The eMCO allowed to reduce the crew from 2 to 1, only during the cruise phases (e.g Connect project (Airbus, 2022)). In the case of SiPO, this reduction would be effective along the whole flight (e.g. DISCO project (Airbus, 2022)(Fig.1)).

According to European Union Aviation Safety Agency (2021) (EASA), the challenges for eMCO and SiPO in terms of safety are numerous: pilot error, monitoring pilot performance, pilot incapacitation, etc. To meet these challenges and achieve a level of safety equivalent to today's two-pilot operations, solutions must be found, such as ground pilot, virtual assistant, advanced cockpit design with workload alleviation means, capability to cope with pilot incapacitation etc..

Figure 1. DISruptive COckpit project (DISCO) by Airbus that would allow the eMCO and SiPO concept.

2.1 Ground assistant in SiPO context

In this section, we present the consequences of the SiPO concepts and the various proposals made by researchers to maintain flight safety.

Schmid and Stanton (2020) describe various problem in the concept of SiPO: operational, automation, pilot incapacitation, communications, and certifications problem. Some of these problems, such as incapacitation and certification, are not the focus of this paper but have been studied by many authors (Paz Goncalves Martins et al., 2021; Schmid and Stanton, 2019). Some projects such as HARVIS (Human Aircraft Roadmap For Virtual Intelligent System) (Duchevet et al., 2020), NiCO (Next generation Intelligent Cockpit) (Niermann and Kügler, 2021), and the Clean Sky project (CleanAviation, 2022), focused on a virtual assistant to assist the pilot on board in specific situations where the assistance of a third party is required. For example, in Duchevet et al. (2020), the virtual assistant provides help for decision making during non-stabilized approaches by alerting the pilot about a deviation from his trajectory.

Other authors are working on the creation of a new cockpit and ground station to assist the pilot on board (Niermann and Kügler, 2021; Lachter et al., 2014b). All these proposals implies different technologies. Some solutions are oriented towards human-machine interaction while other are oriented towards human-human interaction.

2.1.1 Operational solutions for ground assistance

Proposals by industry and researchers for ground support raises new problems of organization and roles between the two pilots. To do so, three concept of operations have been made to support the on-board pilot thanks to a ground assistance: the Hybrid Ground Operator Unit (HGO), the specialist Ground Operator Unit (SGO), and the Harbor Pilot concept (Bilimoria et al., 2014). These three proposals are distinguished by the allocated tasks to the ground assistants (see Fig. 2).

The Hybrid Ground Operator Unit will carry out three types of activities:

- conventional dispatcher tasks (management of flight plans and routes, communication with airlines etc.)
- the monitoring of multiple nominal flights
- the individual support of non-nominal flights

The hybrid ground assistant is dedicated solely to the non-nominal flight in order to provide exclusive support to the aircraft concerned.

The second proposal by Bilimoria et al. (2014) is the Specialist Ground Operator Unit. In this case, two groups form the unit: the Ground Associate and the Ground Pilot or Dedicated Pilot. The first group will be in charge of dispatch duties and nominal flight monitoring. Contrary to the Hybrid Ground Operator unit, ground associates will not deal with non-nominal flights. These flights will be redirected to the dedicated pilot who will be responsible for the individual support of the aircraft in critical situation. When the dedicated pilot does not support the

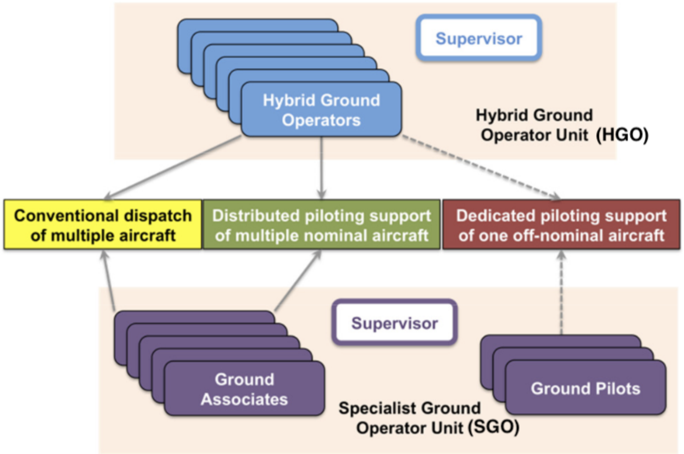

Figure 2. The two ground unit possibilities (Hybrid and Specialist Ground Operator) with in the middle the three tasks of ground unit (Bilimoria et al., 2014).

non-nominal flights, the dedicated pilot will be "on standby or performing collateral duties" (Bilimoria et al., 2014).

In addition to the other two proposals, the Harbor Pilot will support the aircraft in a defined area known to be complex in the case of aircraft ascending or descending. The objective is to decrease the workload of the pilot on-board.

3 Related Work

In this related work, we will present studies about the impact of remote collaboration in SiPO context and the authors' approach to the problem of remote pilot collaboration. In a second step, we will try to address the problem of distance between pilots with an approach focused on awareness during remote collaboration.

3.1 Impact of remote collaboration in allocated pilots tasks

Today, the pilot's tasks are divided into four categories: piloting, navigating, communicating and systems management (Billings, 1997). Each task requires cooperation, coordination and communication between pilots. However, these collaboration processes are achieved through the co-location of the pilots inside the cockpit. With the change of cockpit (automation, crew member, system) and the existence of a ground pilot, the collaboration between pilots will be impacted by the distance. Indeed, the physical separation of two pilots in the actual cockpit cause the loss of non-verbal communication (such as gestures, posture, etc.). To be more precise, the loss of non-verbal communication leads to uncertainty of roles between pilots, uncertainty of actions, uncertainty of manipulation, gathering information and decision making problem (Lachter et al., 2014a). This loss of

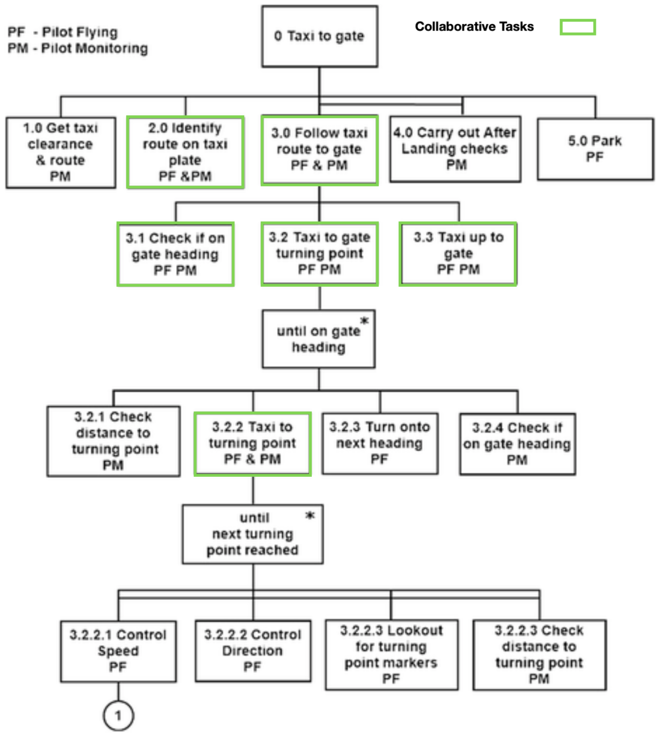

Figure 3. Hierarchical task analysis during taxi to gate with collaborative tasks in green adapted from Huddlestone et al. (2015).

non-verbal communication will therefore disrupt the coordination and consequently the collaboration between the two pilots. For example, the "taxi to the gates" phase requires five collaborative tasks between the two pilots. If the two pilots do not coordinate for the identification of the taxiway (see Fig. 3 : 2.0 "Identify route on taxi Plate"), either through the physical environment (direct view of the runways) or the airport layout, then they could, for example, miss the turn off. In such situation, the integration of new collaboration tools are needed to avoid a degradation of the collaboration.

The studies of remote collaboration in SiPO context (Lachter et al., 2014a,b; Ligda et al., 2015; Brandt et al., 2015; Lachter et al., 2017) show us a lack of awareness in remote collaboration that is addressed by several types of tools. In Lachter et al. (2017), three prototypes of ground station with collaboration tools have been designed and tested (see Fig. 4).

In this approach, the aim is to address the uncertainties in action, manipulation, role, the problem of gathering information and decision making (see section 3.1). For the uncertainty of the roles between the "Pilot Flying" (PF) and "Pilot Non Flying" (PNF) (currently called "Pilot Monitoring" (PM)), the addition of a Crew Resource Management indicator was implemented in the cockpit on board and in the Ground Station. This tool, consisting of 6 LCD touch screens, allows the tracking of responsibilities and actions. One of the screens allows the allocation of roles by displaying "PF" or "PNF". When the role is assigned to one of the pilot,

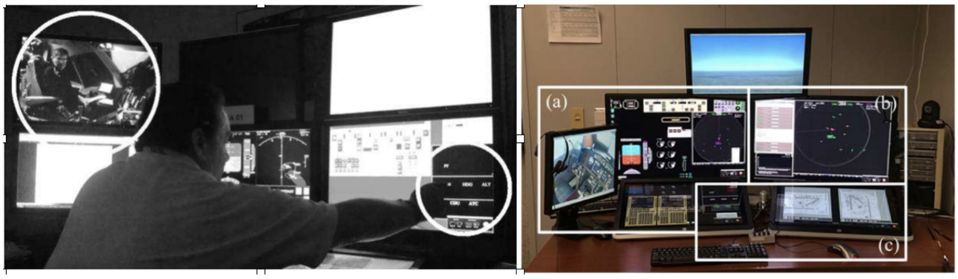

Figure 4. Ground Station (Lachter et al., 2014b) (left). The SiPO III ground station (Lachter et al., 2017; Dao et al., 2015) (right) (a) replicated flight deck displays for the chosen aircraft; (b) flight tracking displays with ELP recommendations; and (c) crew collaboration tools including shareable charts; (d) the Traffic Situation Display and Emergency Landing Planner recommendations (lower left corner).

the other five screens associated with the pilot's tools turn green if the pilot is "PF", or white if the pilot is "PNF". For example, if the first screen showed "PF", then LCD screens below the Mode Control Panel which show "SPD", "HDG", "ALT" turn green and the screen which show "ATC" and "CDU" turn white (see Fig. 4). The CRM indicator also solves the problem of uncertainty of manipulations and actions by indicating with an arrow if the changes in speed are going up or down (manipulations). When the desired value is reached, the speed is displayed and must be validated by the pilot by pressing the touch screen. In addition to the CRM indicator, the video feedback made it possible to see the actions of the two pilots and what they were watching (e.g. MCP, CDU, checklist, etc.). Finally, for gathering information and decision making, the shared maps contained in the Electronic Flight Bag (EFB) could be consulted in a synchronized way.

3.2 Awareness approaches and concepts

Awareness in collaboration tools is an extensive topic with many proposals (Gutwin et al., 1996; Hill and Gutwin, 2003; Greenberg and Gutwin, 2016; Bravo et al., 2013). During collaboration the pilots must have good situation awareness (the perception, comprehension and projection of action and event in our own environment) (Endsley, 2017). To obtain this situation awareness, the pilots must be aware of each other's implicit and explicit activities during the remote collaboration (i.e mutual awareness).

In order to specify whether the integration of awareness is taken into account, Antunes et al. (2014) has created a more complete checklist taking into account a bigger number of awareness concepts than Gutwin et al. (1996) and a questionnaire making it possible to evaluate awareness in groupware. Antunes et al. (2014) showed that six awareness concepts can be used for collaboration tools: collaboration awareness, location awareness, context awareness, situation awareness, social awareness and workspace awareness. This framework of awareness will be used to interpret the results of our case study.

3.2.1 Situation Awareness

Situation awareness allows a "generalization of the notion of workspace". Indeed, the working environment (cockpit, ground station) plays a role in the decisions of both pilots. In order to obtain adequate decisions, the pilots must perceive their environment, understand it and project the consequences of their actions on the environment (Endsley, 2017). In the case of remote collaboration in SiPO, the two pilots do not have the same environment, so it is crucial that each pilot is aware of the impact of their action on the collaborator's environment.

3.2.2 Mutual awareness: a consideration of implicit actions

In a cockpit, pilots will manage to coherently integrate their actions in a discrete way in order to achieve a common goal. This awareness of each other's activity can be communicated explicitly (oral or digital communication) or implicitly (intonation in the voice, modulation of gestures) during an action. These are the implicit actions, called "discrete action" (Schmidt, 1998).

According to this author, the awareness between two people is not only an explicit fact allowing to coordinate these activities. It is a whole that also includes the implicity of actions. This set called mutual awareness is "the perception and understanding of the activities of member A, including the intention, status and possible outcomes of that activity, by member B" (vice versa) (Schmidt, 1998). In a remote collaboration, it is a question of a loss of information that the collaborator transmits, what it looks like, whether it is permanent to whom it is transmitted and what the intentions of those who use this information are going to be (Bellotti and Sellen, 1993).

Mutual awareness has already experienced problems in the field of aeronautics and more precisely in touch screens (Becquet et al., 2019). Indeed, the loss of tangible elements leads to an abstraction of actions (implicit or explicit) and a loss of information for the collaborator during the manipulation of an object. More generally, mutual awareness emphasizes the combination of attention directed towards a collaborator (focus) and the way in which this collaborator projects his presence and his activities towards him (nimbus).

3.2.3 Collaboration Awareness

Collaboration awareness corresponds to the perception of the availability of the two collaborators (Group availability) and the mode of communication used. The availability of the group of pilots is distinguished by the relative position of the two collaborators (same place or different place) (Johansen et al., 1991) and if the pilots are online or not (Schmidt, 2002). Concerning the mode of communication, it can be synchronous, asynchronous or even semi-synchronous. This reduction in mental distance will allow a better projection of the situation for the ground support and the feeling of being in a crew. The characteristics of this awareness allow us to suppose its importance in communication tasks, especially for the need to obtain the availability of the collaborator but also for the awareness of the communication mode.

3.2.4 Location Awareness

According to Antunes et al. (2014), location awareness refers to the geographical position of collaborators and more precisely to the awareness of the position, topology and attributes of the space (e.g. weather, temperature). In the case of a non-nominal situation, it is important for the ground support to know the geographical position of the pilot on board. Indeed, the indication of weather conditions (storm, wind) and also topography (sea, land, mountain) allows ground pilot to adapt his decision making.

3.2.5 Context Awareness

Context awareness is related to virtual space (computer-based interactive spaces) (Rodden, 1996). It allows the understanding of changes and events in the virtual space to be maintained between two collaborators. In the case of piloting, the pilots will know where the collaborator is in the virtual workspace like an electronic checklist. For example if the pilot is on page "X", the second pilot will not have to ask where he is in the checklist.

3.2.6 Social Awareness

Social awareness corresponds to the social context during the collaboration between the two pilots. The social context is the understanding between the two pilots of each other's roles and activities but also of what and how the members of the group contribute to a task (Carroll et al., 2003). Indeed, within the framework of the SiPO concept, the roles and activities must be clear when collaborating at a distance. As noted by Lachter et al. (2014a), confusion has been observed regarding the roles assigned to the pilots and their activities while their definition is important in piloting activity.

3.2.7 Workspace awareness

According to Snowdon et al. (2000), the workspace corresponds to "a container of places with continuous activities". It is possible to focus on place, which allows the organization of tasks (who, what, when, how) as allowed by group editors (writing, revising, global activity view) (Koch and Koch, 2000). For example, the on-board pilot knows that the pilot on the ground (red tack, who) is in the process (real time, when) of highlighting (tack, what) an airport on a shared map, thanks to a marking system (planting tack, how).

3.2.8 Informal Awareness

We can identify an additional awareness possibly impacted by SiPO : the informal Awareness related to the need for informal communication. Indeed, according to Röcker (2012), informal awareness is "similar to informal communication". As far as informal communication is concerned, it is necessary for the smooth running of a crew because it allows the two pilots to obtain an awareness preview of the situation. This informal communication makes it possible to defuse situations before they become critical via discussions in the corridor or with one's office neighbor (Mackay, 1999). In the case of a standard configuration in the cockpit, the two pilots can have informal discussions during phases when the workload is reduced (cruise phase) and obtain a more important situation awareness.

Awareness	**Example in a flight context**	**Problems identified by Lachter et al. (2014b)**
Collaboration	The pilot on the ground knows that the pilot on board is available to collaborate	No problems identified
Location	Both pilots know where the other is geographically located	No problems identified
Situation	Both pilots see and understand each other's actions and their consequences on the cockpit	Action uncertainty
Social	What roles are assigned to each of the two pilots and what are their activities	Role uncertainty
Context	Both pilots know which page the pilot is on when consulting the QRH	Action uncertainty Gathering information Decision making
Workspaces	Both pilots know who, what, when and how tasks are performed in the workspace	Manipulation uncertainty Gathering information Decision making

Table I. Categorization of uncertainties identified by Lachter et al. (2014b) through Antunes' Awareness in a flight context.

In this paper, we choose to study the awareness proposed by Antunes et al. (2014) for his more comprehensive list of awareness as well as the informal awareness described by Röcker (2012). The application of the Antunes et al.

(2014) framework on the problems raised by Lachter et al. (2014a) allows us to bring some precisions on the lack of awareness in SiPO context (see Table I.).

4 Methodology

To analyze the awareness problem as accurately as possible, we conducted a series of activities. The first step was to study actual pilot task in real flight conditions and in simulations, using videos and interview transcripts generated in a previous project (Letondal et al., 2018). Following this study, we decided to set up a remote collaboration situation with the aim of clarifying awareness needs in collaboration with three pairs of commercial airlines pilots. In this case study, we separated two pilots in two different rooms in a low-fidelity cockpit (computer, flight simulator, and yoke) to observe the consequences of remote collaboration in a non-nominal flight (unusual situation). After this remote collaboration situation, we conducted an interview (1 hour, right after the simulation) with the pair of pilots to provide an analysis of awareness needs in remote collaboration. To extract the maximum information from these interviews, we identified the different insights associated with awareness and collaboration. Then, we associated different keywords to quotes such as "informal communication", "verbalization" , "action", "perception", "action monitoring". Finally, we carried out exploratory prototyping to refine awareness concepts of SiPO.

5 Case study: a flight with the two pilots separated

In this section, we describe our case study that we conducted to understand the impact of separation. In this study, we chose, while using a current airliner cockpit (A320 cockpit simulator), to introduce an artifact by dividing the cockpit in two and putting each pilot in a different room. Our goal was thus to isolate the distance dimension by moving from co-located collaboration to remote collaboration without changing the rest. We were counting on this device to observe the effect of separation and distance in the behavior of the pilots, in particular to identify what in this behavior would be a problem of mutual awareness without perception of gestures, bodies, head directions, etc., of the other pilot. In addition, to accentuate the problems of mutual awareness, we opted for a non-nominal, but nevertheless usual situation in pilot training.

5.1 Participants and setting

In our experiment, six airline pilots were divided into tree pairs of *Pilot Flying* and *Pilot Monitoring*. The 3 pairs of pilots can be categorized according to the number of flying hours (Table II.). Pairs A and B have a real experience of Multi-Crew Cooperation (MCC) experience, while Pair C has not MCC experience outside the simulator.

Couple	Age	Flight hours
P1.A	44	9200
P2.A	43	8400
P3.B	45	4500
P4.B	33	3500
P5.C	30	230
P6.C	21	410

Table II. Categorisation of participants.

5.2 Material

The pilots were separated in two different rooms. In each room, the pilots were placed in front of a computer running MICROSOFT FLIGHT SIMULATOR 2020 (MFS2020), with a community mod called YourControl, allowing cockpit sharing and synchronization of the two MFS2020 licences. To control the flight path, the pilots were equipped with a Honeycomb Alpha Flight Controls stick. The simulation takes place on an Airbus A320 and each pilot has a Quick Reference Handbook (QRH) associated with the aircraft.

Figure 5. Video editing of the two pilot in low fidelity cockpit and the cockpit screen capture.

5.3 Flight scenario

First of all, a briefing took place with the pilots concerning the flight conditions. After providing the flight briefing, the pilots were assigned the roles of pilot flying and pilot monitoring and went to two separate rooms. The flight, departing from Gran Canari (GCLP) to Gatwick (EGKK), started directly on the runway for the take-off phase. Pilots were only instructed that they were at FL350 during the cruise phase. On arrival at the waypoint (VASTO), a cabin smoke alert was announced by one of the fictitious cabin crew. Following this announcement, we decided to stop the simulation when the pilots arrived at the PACK 2 item of the

A320 QRH cabin smoke procedure. The whole scenario was recorded with two cameras facing each pilot and the screen recording of the MFS2020 simulator. Following the scenario, interviews were conducted for approximately one hour. These interviews were transcribed and analyzed qualitatively.

5.4 Results

As a result of the interviews and the transcriptions, we were able to gather some insights to specify needs to achieve mutual awareness. From the interviews, we identified the different awarenesses impacted by remote collaboration in a current cockpit.

Social Awareness needs During the remote collaboration, the coordination between all pairs of pilots was not equivalent. Some of them had coordination problems, as both pilots were not aware of the roles and activities that each of them had to perform at the beginning of the flight, while the roles were predefined during the briefing.

> (1)(P6.C) : "so at the beginning we were a little bit [...] not well ordered because we didn't know who had to do what actions and all that [...]"

This confusion, which we can see in the quote (1), is caused by a lack of awareness regarding the distribution of roles. This finding is consistent with the problems identified by Lachter et al. (2014a) regarding role uncertainty during remote collaboration between the two pilots. Without the appropriate tools to make both pilots aware of each other's roles in the remote collaboration, we noticed that remote collaboration mainly impacted coordination.

Context Awareness needs Other problems identified during the interview concerned context awareness. Indeed, when handling the QRH, the two pilots had no idea of the position of the collaborator in the QRH when they consulted it as the following quote shows :

> (2)(P6.C): "in fact it's not badly done in the sense that it has pages with numbers a moment ago I told you but wait [...] no, it was you who told me ... and so it was important to have a well-established QRH with references so that you don't get confused and it's also important to make it clear which page you're on, especially when you can't see yourself, especially when you can't read the page directly [...]"

This confusion can be easily solved by a computerized and synchronized QRH between the two pilots. This way both pilots will know where the pilot is looking in the QRH. This need for awareness seems to be associated with coordination in the 3Cs model, in that elements of context awareness such as the other's view or position in the QRH allows them to improve their coordination and therefore their communication to reach a decision (cooperation).

Workspace awareness needs In our case study, verbal communication is accentuated to express actions that may not be perceptible to the second pilot. This emphasis allows to highlight some important elements to be transcribed at system level in the future SiPO cockpit. For example, the accentuation of FCU (Flight Control Unit) modifications on the ground pilot interface to allow on-board pilot to be aware the modifications without verbal communication.

It is important to note that the verbalization of one of the pilots make the other pilot, who is not aware of these characteristics, aware of the actions, intentions and emotional states. As a result, pilots do not know when, what, how, the action are made in their workspace (i.e the cockpit) without verbalization.

This increase in verbal communication can be associated with a lack of workspace awareness. As each pilot was not sure whether the other was aware of the other's actions and intentions, the pilot making the changes in the cockpit would verbalize everything he or she did. This is in contrast with current rules, as explained by this pilot :

> (3)(P2.B) : "So we [...] we don't verbalize any more [...] in fact P3.B, being in manual piloting with change of altitude it's automatic that it's the PM who displays it and we have the non verbal action in the visual field the PF sees that there is an action on the switch of the altitude that there is [...] Whereas I was verbalizing it I put the altitude on and then I made the official announcement [...] the cross checker behind. Usually I don't say I'm putting the 350 level on automatically"

This accentuation of verbalization allow pilots to mentally reconstruct the actions performed in the cockpit as this quotation shows :

> (4)(P3.B): "[...] I could see that he was setting things, I could see everything he was setting, everything he was setting he was saying so I could see it".

The accentuation of verbalization during our case study show us a lack of coordination which can be resolved through workspace awareness elements that show who, what, when and how actions are performed in the environment.

Informal awareness needs One of the operational problems of the SiPO concept concerns the feeling of crew and more precisely the relationship between two pilots in a cockpit.

(5)(P6.C) : "the fact that I knew him I found it easier to communicate with him [...] a little more fluid and I dared to speak more and propose things, whereas what I remember in MCC (Multi Crew Cooperation), the fact that I didn't know the person, I dared to propose things perhaps less"

(6)(P3.B) : "The fact that we were talking like that, you were next to me Yeah, so I had I didn't have the presence but I still had the presence of the voice"

Informal communication makes it possible to defuse situations before they become problematic (Mackay, 1999). This communication also contributes to the sense of crew, an important feeling among pilots. In the SiPO concept, the pilot alone cannot communicate informally with the ground if the ground is not available. This lack of awareness brings us very clearly closer to a communication problem in the 3Cs model.

5.4.1 Conclusion of the case study

From the different interviews we can see that most of the awareness concepts has been strongly impacted by remote collaboration in a standard cockpit. In the case of collaboration in a current cockpit: context awareness, social awareness, informal awareness and workspace awareness seem to be low. However, we observed that the location awareness (awareness of the position, topology and attributes of the space (e.g. weather, temperature) and collaboration awareness (perception of the availability of the two collaborators and the mode of communication used) described by Antunes et al. (2014) were intact because both pilots are in the same virtual cockpit synchronized by the add-on with direct communication. Concerning mutual awareness and situation awareness, we noticed that both awareness are impaired in remote collaboration in SiPO context. Indeed, situation and mutual awareness are part of an overall awareness when collaborating which allow pilots to coordinate, cooperate and communicate. Finally, to achieve this mutual awareness in SiPO context, a subset of awareness is needed as context awareness, social awareness, informal awareness and workspace awareness.

6 Exploratory Prototyping

Exploratory prototyping activities were conducted to refine our understanding of collaboration awareness, context awareness, workspace awareness, social awareness and situation awareness in situated and concrete scenarios involving an on-board pilot and a ground pilot. Table III provides an overview of explored awareness concepts in each prototype. Two pilots were involved during prototypes 2 to 7, one of whom participated in the simulation (P3.B) and a second pilot who was not present at any of the stages of our approach.

Awareness	Prototype number
Collaboration	1,2,3
Context	4,5
Situation	7
Social	6
Workspace	6

Table III. Table of the different prototypes proposed according to awareness.

The prototypes were designed on the basis of scenarios that are provided in Table IV. Two of the scenarios are based on non-nominal situation (Non-stabilized approach and Rerouting) and one is during a nominal situation (Taxiing).

Scenario	Description	Prototypes	Awareness
Non-stabilized approach	Non-stabilized approach of the aircraft requiring high physical and mental concentration.	3	collaboration
Rerouting	Rerouting solution due to a medical emergency requiring a decision between the pilot on board and the pilot on the ground.	1,2,4,5	context social workspace
Taxiing	Ground guidance scenario on arrival (taxiing) requiring tools to provide the ground operator assisting the pilot with a global awareness of the course of the flight.	6	situation

Table IV. Table of the different scenario according to prototypes.

6.1 Exploring collaboration awareness design

The aspect of collaboration awareness studied in the following prototypes are availability and communication mode as described by Antunes et al. (2014).

Availability has been explored in several forms: clock indicator, physiological data visualizations and by a "check mark" icon on a shared tool. The communication mode has been explored through a synchronous or asynchronous mode indicator in a shared map.

Prototypes 1 and 2 and their design elements presented below are integrated into a shared map for a rerouting scenario where one of the passengers suffers a heart attack. Faced with this medical situation, the pilot on board and the ground pilot must agree on a diversion airport as soon as possible, according to different criteria and views (weather, terrain).

6.1.1 Prototype 1: a clock to indicate asynchronous actions

The first prototype is included in an asynchronous shared map between ground and on-board pilot. When the clock is displayed, it indicates that the other pilot is busy with an action in progress (e.g. a choice of diversion scenario) performed asynchronously (Fig. 6 and 7).

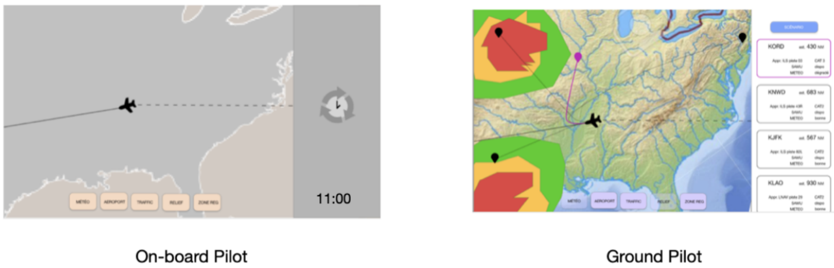

Figure 6. Prototype 1 Clock Design: Shared maps with on the left the on-board pilots' screen and on the right the ground pilot' screen. The ground pilot selects a diversion scenario on the left of his screen. On the left-hand side of the pilot's screen, a "clock" indicates that scenarios are being chosen by the pilot on the ground.

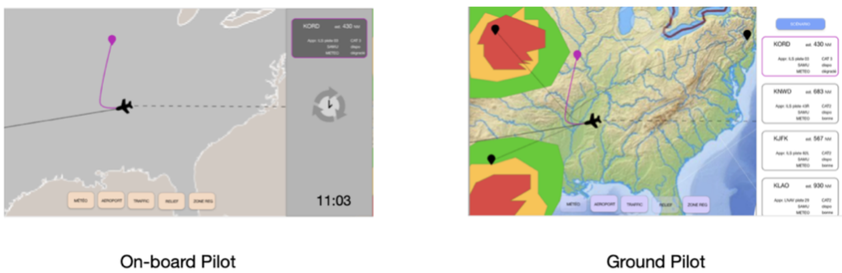

Figure 7. Prototype 1 Clock Design: Shared maps three minutes after choosing a diversion scenario, it is sent to the shared map of the pilot on board. The clock always present, indicates that a second scenario is chosen by the pilot on the ground.

6.1.2 Prototype 2: Availability check mark

A second availability indicator has been designed in the form of a green check mark when the other pilot is available and a red cross otherwise (Fig. 8). An overview of the other pilot's screen completes this information.

6.1.3 Prototype 3: Physiological state widgets

The 3rd prototype proposes indicators of the physiological state of the pilot on board. These indicators could for example be useful in an non-stabilized approach

Figure 8. Prototype 2: Shared maps with availability indicators on the left on on-board pilot' screen and ground pilot' screen. A) a green check-mark indicates the availability of the ground pilot to collaborate B) a red cross shows the unavailability of the on-board pilot ; overviews of the other pilot's screen are provided.

scenario, requiring a good understanding of the other pilot's ability to cope with a difficult situation. Five indicators (Heart Rate, emotions, Galvanic Response Skin, side stick input and gaze indicator) (see Fig. 9), are provided to help the ground assistant to adapt his communication according to the pilot's physiological state.

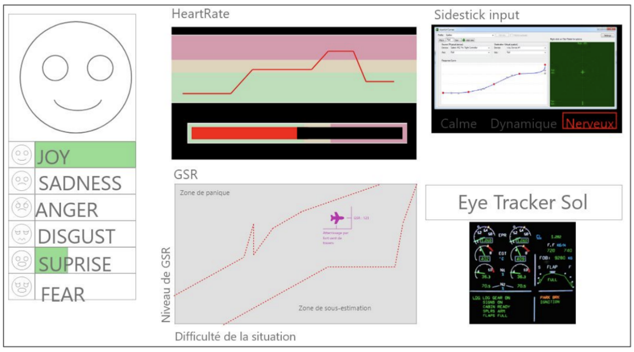

Figure 9. Prototype 3: Physiological state widgets. Left: an emotion indicator; Heart Rate and Galvanic Response Skin (GRS) indicators. Right: side stick input of the on-board pilot and gaze tracker that allow ground pilot to see what the on-board pilot is looking at.

The collaboration awareness explored in these prototypes (1, 2, 3), seem to us to be closely linked to awareness elements allowing a communication and coordination support. Indeed, thanks to these 2D on-screen awareness mechanisms (prototype 1, 2) and the sensor-mediated awareness mechanisms (prototype 3), the pilots may or may not engage in a conversation with the collaborator in a synchronous (voice, text chat) or asynchronous (mail) manner.

6.2 Exploring context awareness design

The aspect of context awareness explored in the following prototypes correspond to the view mode and allow pilots to be aware of the navigation of the collaborator in the shared map. The representation of the view mode has been explored in two forms: a red view indicator and a overview indicator. The first design elements presented below are integrated into a shared map.

6.2.1 Prototype 4 and 5: view indicator

Inspired by the "radar views" of Gutwin et al. (1996), the red view indicator allow pilots to get the position of the view screen of the other pilot.

In the case of the synchronous shared map, both users can interact with the map and propose different rerouting solutions. To coordinate their action and communication, both pilots must have the same information displayed on the map.

Figure 10. Prototype 4: First design of view indicator on remote synchronous shared map. Left: on-board pilot' screen with view indicator of ground pilot' screen in red. Right: Ground pilot' screen with view indicator of on-board pilot' screen.

To do this, we added a view indicator when the two pilots are not positioned at the same view on the map (see Fig. 10). A red dot with an arrow indicates the position of the other pilot's view (e.g. to the right slightly above). To get the same view as the other one the pilots have to click on the dot.

This tool is appropriate whenever the impact of context awareness can cause a disruption of social awareness. As this quote shows:

> (P2.A): "and yes [...] so we both ended up with the QRH when one is supposed to fly [...]"

In this case, both pilots were forced to check the QRH (Quick Reference Handbook) because one of the pilots could not find the item concerning the "cabin smoke" situation (see section 5.4). Afterwards, they started a discussion about the supposed item but realized that it was not on the same page. We supposed that this loss of context awareness, highlighted by this quote, can be observed when consulting a map.

In the next prototype, an overview was added so that the pilot is able to see directly the view and the position of the other pilot's view (see Fig. 11).

The two awareness elements inform about the view of the other pilot and should help their coordination when talking about a precise area of the map.

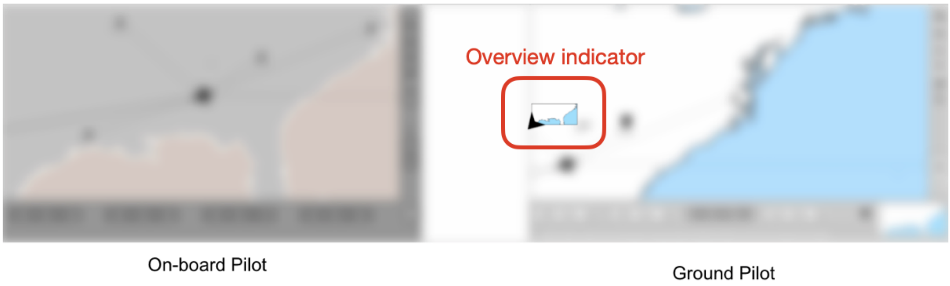

Figure 11. Prototype 5 : Second design of view indicator on remote synchronous shared map. On the left: on-board pilot' screen. On the right: Ground pilot' screen with view indicator of on-board pilot' screen.

6.3 Exploring workspace and social awareness design

The use of pointers for the map have been already used to support workspace awareness (Greenberg et al., 1996). It allows the pilot to know who, what, when, how he is manipulating the map. Indeed, we observed that in the interviews the accentuation of the verbalization allows to obtain a better workspace awareness. Although verbal communication will be maintained in the remote collaboration, we propose here a support to obtain information on who (name of the person on the mouse) is manipulating the map (what) when (screen synchronization) and how (using the mouse) (see Fig. 12).

6.3.1 Prototype 6: telepointers

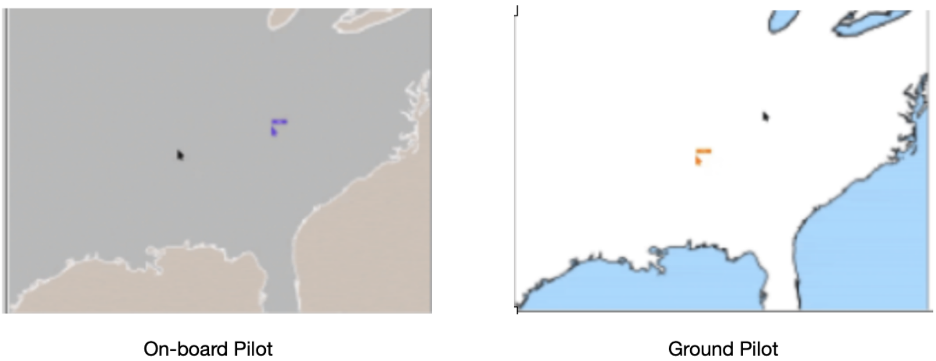

Figure 12. Prototype 6: Two pointers on shared maps (relaxed WYSIWIS) with on-board pilot (black pointer) and ground pilot (blue pointer) for on-board pilot screen. And on ground pilot' screen, an orange pointer that represent on-board pilot pointer and a black that represent his own pointer.

The idea of a telepointer seems to be a key element of the SiPO concept, as the two pilots explain:

> (P3.B) : "uh [...] I know that at home we show the checklist a lot"
> and

(P4.B) :" yeah you point to this checklist and you confirm [...]"

In addition, the color of the mouse indicates who has control over the shared map. When one of the pilots manipulates the map, the cursor changes color (here in blue, see Fig. 12) for the observer. When the other pilot is manipulating the map, there is a switch of roles within the collaboration tool and therefore of the cursor colors. Therefore, this design element improves social awareness by defining the role and activity in the tool.

We suppose that this element of workspace and social awareness can support coordination between the two pilots. Indeed, the two awareness elements, based on 2D on-screen awareness mechanisms (i.e. scroll bar, telepointers, chat tool or participant list (Hill and Gutwin, 2003)), inform about the actions provided in the shared map and allow pilots to coordinate their action on the shared map.

6.4 Exploring situation awareness

6.4.1 Prototype 7: Flight Timeline

The following prototype (see Fig. 13) provides an overview of the events occurring during the course of a flight in order to support situation awareness which might be necessary for a dedicated assistance. For instance, thanks to this timeline, a ground operator in a taxiing procedure would have a global awareness letting them better understand the behavior of the pilots, or assess the risk for them to miss a taxiway.

Possible examples of events include for instance switch to Automatic Pilot (AP), altitude changes, heading changes, ATC request, meteorological, systems failures or comments from the pilots. As the pilots explain :

> (P3.B) "I thought to myself that it reminded me a little of the mechanic [...] the sailor who was at the back [...] I have this [...] with a global view even if he was overloaded because he had more work too"

and

> (P4.B) : "no, but I was saturated [...] if he's suddenly reconnected like that, he needs the flight history, he needs to know where he is, the AP mode"

This timeline also gives access, by selecting a phase, to tools to monitor this phase more precisely (e.g. checklist, fuel, map, etc).

6.5 Feedback from pilots

The main aim of the exploration prototypes was to instantiate the concepts of awareness described in section 3. The designs were discussed with pilots to get feedback regarding awareness as well as usability. One of the most important feedback from the pilots was that the need for awareness is asymmetrical to the

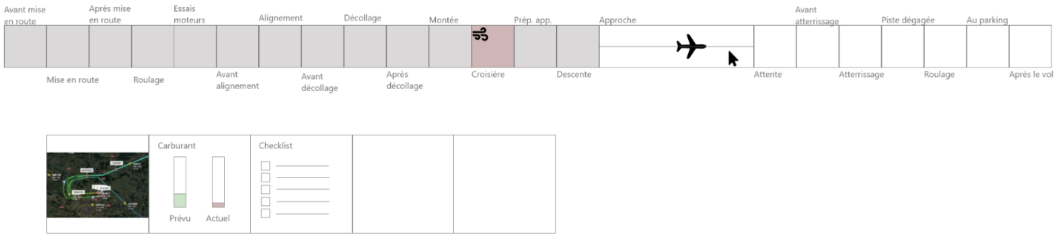

Figure 13. Prototype 7: Flight Timeline displaying notable events during the different phases of a flight. Adding flight information is possible depending to the phase.

pilots' role (on-board or ground). Indeed, the addition of awareness elements for the pilot on board can be disruptive if the pilot does not choose to see these elements. This was confirmed by their request to decide themselves about the synchronicity of the map. In other words, pilots want to be able to choose between a relaxed WYSIWIS (What You See Is What I See) different views on their shared workspace (Greenberg, 1996) and a WYSIWIS (view shared between the users is identical)(Stefik et al., 1987). Concerning Prototype 3., pilots suggested that we should notify the pilot on the ground of abrupt changes and variations in these physiological values instead of continuous data. For the view indicator, the pilots seems to appreciate the idea with a preference for the Prototype 4. This preference is justified by its minimalism and the information transmitted. According to the pilots, prototype 5 is too large for the information given. Moreover, feedback was given on the color of the awareness elements (prototype 4, 5). For example, using red for the view indicator is inappropriate because this color is by convention a color associated with an urgent action to take. Finally, in Prototype 7, the pilots suggested that the timeline could be used as a reminder. This implies the addition of a possible shared editor inside the timeline. The shared editor could, according to the pilots, change the color of a phase, add icons, change the color of the icons or add markers.

7 Discussion and future work

In this section, we first discuss the contribution of this paper in refining the understanding of the awareness problem and secondly point out possible other problems in remote collaboration in SiPO context.

In our approach, we propose to refine the general awareness problem exposed by Lachter et al. (2014a), by applying awareness frameworks used for remote collaboration tools. These different proposals by Antunes et al. (2014), Schmidt (1998), and Gutwin et al. (1996) show us the range of awareness identifiable to support coordination, cooperation and communication in remote collaboration. In our case study and exploratory prototyping, we notice that the interpretation of awareness provided by Antunes et al. (2014) and Schmidt (1998) seems to be adapted to identify the need for awareness in future SiPO tools. Indeed, the specification of social, workspace, context, situation and informal awareness in mutual awareness will allow us to specify the design of future remote collaboration tools in SiPO context.

Implicit interactions (Schmidt, 2000) have not been addressed in our case study nor in exploratory prototyping. A further step would therefore be to design awareness elements for this purpose. For example, to transmits implicit information of navigation interaction we can imagine a gradient of the indicator's red color to signify the type of interaction the pilot on board has on the shared map (unfinished, touch-and go, full interaction) (implicit interaction) (see Prototype 4).

To further refine the awareness problem, one of the points raised by the pilots is the relevance of awareness needs according to the role (on-board pilot and ground pilot). For instance, location awareness (to know where the ground pilot is geographically located) may be not necessary for the on-board pilot. To identify awareness according to roles, a possibility might be the utilization of the questionnaire by Antunes et al. (2014) (questionnaire to find out if the targeted awareness is implemented in the tool) and ask to the pilot if this awareness is necessary for the remote collaboration depending of their roles.

Another point to raise, is the need of awareness throughout the flight. We can suppose that the needs in terms of assistance will not be identical according to the phase of flight (variation of mental availability) or the situation (non-nominal, nominal).

The other aspects to be taken into account in the continuation of this study will finally be the impact of the automation and the reconfigurations to adapt to the various phases of flight, as well as the aspects of the collaboration between the operators on the ground dealing successively with the same flight.

8 Conclusion

In this paper, we proposed a specification of the awareness problem during remote collaboration in a new aeronautical context, the Single-Pilot Operation (SiPO). Thanks to our description of awareness frameworks applied in SiPO, our case study and our exploratory prototyping, we specified context awareness, workspace awareness, social awareness, informal awareness as key elements to design remote collaboration tools in this context. Finally, we illustrated them in the context of concrete scenarios and prototypes.

References

Airbus (2022): 'Autonomous flight'. In: *https://www.airbus.com/en/innovation/autonomous-connected/autonomous-flight*.

Antunes, P., V. Herskovic, S. F. Ochoa, and J. A. Pino (2014): 'Reviewing the quality of awareness support in collaborative applications'. *Journal of Systems and Software*, vol. 89, pp. 146–169.

Beaudouin-Lafon, M. and A. Karsenty (1992): 'Transparency and awareness in a real-time groupware system'. In: *Proceedings of the 5th annual ACM symposium on User interface software and technology*. pp. 171–180.

Becquet, V., C. Letondal, J.-L. Vinot, and S. Pauchet (2019): 'How do Gestures Matter for Mutual Awareness in Cockpits?: Disclosing Interactions through Graphical Representations'. In: *Proceedings of the 2019 on Designing Interactive Systems Conference*. p. 593–605, ACM.

Bellotti, V. and A. Sellen (1993): 'Design for privacy in ubiquitous computing environments'. In: *Proceedings of the Third European Conference on Computer-Supported Cooperative Work 13–17 September 1993, Milan, Italy ECSCW'93*. pp. 77–92.

Bilimoria, K. D., W. W. Johnson, and P. C. Schutte (2014): 'Conceptual framework for single pilot operations'. In: *Proceedings of the international conference on human-computer interaction in aerospace*. pp. 1–8.

Billings, C. E. (1997): 'Aviation Automation the Search for a Human Centered Approach Lawrence Erlbaum Associates'. *Inc., Mahwah, NJ*.

Bohn, R. E. (2010): 'How flying got smarter'. In: *2010 IEEE Intelligent Vehicles Symposium*. p. 682–687, IEEE.

Brandt, S. L., J. Lachter, V. Battiste, and W. Johnson (2015): 'Pilot Situation Awareness and its Implications for Single Pilot Operations: Analysis of a Human-in-the-Loop Study'. *Procedia Manufacturing*, vol. 3, pp. 3017–3024.

Bravo, C., R. Duque, and J. Gallardo (2013): 'A groupware system to support collaborative programming: Design and experiences'. *Journal of Systems and Software*, vol. 86, no. 7, pp. 1759–1771.

Carroll, J. M., D. C. Neale, P. L. Isenhour, M. B. Rosson, and D. S. McCrickard (2003): 'Notification and awareness: synchronizing task-oriented collaborative activity'. *International Journal of Human-Computer Studies*, vol. 58, no. 5, pp. 605–632.

CleanAviation (2022): 'At the sharp end: Innovative cockpit tech points the way'. In: *https://clean-aviation.eu/media/results-stories/at-the-sharp-end-innovative-cockpit-tech-points-the-way*.

Council, N. R. et al. (2014): *Autonomy research for civil aviation: toward a new era of flight*. National Academies Press.

Dao, A.-Q. V., K. Koltai, S. D. Cals, S. L. Brandt, J. Lachter, M. Matessa, D. E. Smith, V. Battiste, and W. W. Johnson (2015): 'Evaluation of a recommender system for single pilot operations'. *Procedia Manufacturing*, vol. 3, pp. 3070–3077.

Duchevet, A., G. Granger, J.-P. Imbert, T. De La Hogue, A. L. R. Vasquez, J. N. Sanchez, J. M. M. Garcia, S. Bonelli, and A. Ferreira (2020): 'Toward a Non Stabilized Approach assistant based on human expertise'. In: *ICCAS 2020, 1st International Conference on Cognitive Aircraft Systems*.

Endsley, M. R. (2017): 'Toward a theory of situation awareness in dynamic systems'. In: *Situational awareness*. Routledge, pp. 9–42.

European Union Aviation Safety Agency, E. (2021): 'Horizon Europe Project: Extended Minimum Crew Operations – Single Pilot Operations – Safety risk assessment framework'.

Greenberg, S. (1996): 'A fisheye text editor for relaxed-WYSIWIS groupware'. In: *Conference Companion on Human Factors in Computing Systems*. pp. 212–213.

Greenberg, S. and C. Gutwin (2016): 'Implications of we-awareness to the design of distributed groupware tools'. *Computer Supported Cooperative Work (CSCW)*, vol. 25, no. 4, pp. 279–293.

Greenberg, S., C. Gutwin, and M. Roseman (1996): 'Semantic telepointers for groupware'. In: *Proceedings sixth Australian conference on computer-human interaction*. pp. 54–61.

Gross, T. (2013): 'Supporting effortless coordination: 25 years of awareness research'. *Computer Supported Cooperative Work (CSCW)*, vol. 22, no. 4-6, pp. 425–474.

Gutwin, C., S. Greenberg, and M. Roseman (1996): 'Workspace awareness in real-time distributed groupware: Framework, widgets, and evaluation'. In: *People and computers XI*. Springer, pp. 281–298.

Hill, J. and C. Gutwin (2003): 'Awareness support in a groupware widget toolkit'. In: *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*. pp. 258–267.

Huddlestone, J., D. Harris, D. Richards, S. Scott, and R. Sears (2015): 'Dual pilot and single pilot operations–hierarchical task decomposition analysis of doing more with less'. In: *International Conference on Engineering Psychology and Cognitive Ergonomics*. pp. 365–376.

Johansen, R., D. Sibbet, S. Benson, A. Martin, R. Mittman, and P. Saffo (1991): *Leading business teams: How teams can use technology and group process tools to enhance performance*. Addison-Wesley Longman Publishing Co., Inc.

Koch, M. and J. Koch (2000): 'Application of frameworks in groupware—The iris group editor environment'. *ACM Computing Surveys (CSUR)*, vol. 32, no. 1es, pp. 28–es.

Lachter, J., V. Battiste, M. Matessa, Q. V. Dao, R. Koteskey, and W. W. Johnson (2014a): 'Toward single pilot operations: the impact of the loss of non-verbal communication on the flight deck'. In: *Proceedings of the International Conference on Human-Computer Interaction in Aerospace - HCI-Aero '14*. p. 1–8, ACM Press.

Lachter, J., S. L. Brandt, V. Battiste, S. V. Ligda, M. Matessa, and W. W. Johnson (2014b): 'Toward single pilot operations: developing a ground station'. In: *Proceedings of the International Conference on Human-Computer Interaction in Aerospace - HCI-Aero '14*. p. 1–8, ACM Press.

Lachter, J., S. L. Brandt, V. Battiste, M. Matessa, and W. W. Johnson (2017): 'Enhanced ground support: lessons from work on reduced crew operations'. *Cognition, Technology Work*, vol. 19, no. 2–3, pp. 279–288.

Letondal, C., J.-L. Vinot, S. Pauchet, C. Boussiron, S. Rey, V. Becquet, and C. Lavenir (2018): 'Being in the sky: Framing tangible and embodied interaction for future airliner cockpits'. In: *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*. pp. 656–666.

Ligda, S. V., U. Fischer, K. Mosier, M. Matessa, V. Battiste, and W. W. Johnson (2015): 'Effectiveness of advanced collaboration tools on crew communication in reduced crew operations'. In: *International conference on engineering psychology and cognitive ergonomics*. pp. 416–427.

Mackay, W. E. (1999): 'Media spaces: Environments for informal multimedia interaction'. *Computer Supported Co-operative Work*, vol. 7, pp. 55–82.

Niermann, C. and D. Kügler (2021): 'Next Generation Intelligent Cockpit–Single-pilot operations' potential to increase flight safety'. *ECAC News*, no. 74, pp. 25–28.

Paz Goncalves Martins, A., J. Lieb, M. Friedrich, S. Bonelli, M. Celori, and A. de Bortoli (2021): ‘Toward single pilot operations: A conceptual framework to manage in-flight incapacitation’. *11th SESAR Innovation Days: Inspiring Long-Term Research in the Field of Air Traffic Management, SIDs 2021*.

Röcker, C. (2012): ‘Informal communication and awareness in virtual teams’. *Communications in Information Science and Management Engineering*, vol. 2, no. 5, pp. 1–15.

Rodden, T. (1996): ‘Populating the application: A model of awareness for cooperative applications’. In: *Proceedings of the 1996 ACM conference on Computer supported cooperative work*. pp. 87–96.

Schmid, D. and N. A. Stanton (2019): ‘A future airliner’s reduced-crew: modelling pilot incapacitation and homicide-suicide with systems theory’. *Human-Intelligent Systems Integration*, vol. 1, no. 1, pp. 27–42.

Schmid, D. and N. A. Stanton (2020): ‘Progressing Toward Airliners’ Reduced-Crew Operations: A Systematic Literature Review’, pp. 25.

Schmidt, A. (2000): ‘Implicit human computer interaction through context’. *Personal technologies*, vol. 4, no. 2, pp. 191–199.

Schmidt, K. (1998): ‘Some notes on mutual awareness’. *COTCOS, CTI, DTU, Copenhagen, Denmark*.

Schmidt, K. (2002): ‘The problem withawareness’: Introductory remarks onawareness in CSCW”. *Computer Supported Cooperative Work (CSCW)*, vol. 11, no. 3-4, pp. 285–298.

Snowdon, D., E. F. Churchill, and A. J. Munro (2000): ‘Collaborative virtual environments: digital spaces and places for CSCW’. *Collaborative Virtual Environments (2000)*, pp. 1–34.

Stefik, M., D. G. Bobrow, G. Foster, S. Lanning, and D. Tatar (1987): ‘WYSIWIS revised: Early experiences with multiuser interfaces’. *ACM Transactions on Information Systems (TOIS)*, vol. 5, no. 2, pp. 147–167.

Permissions

If the paper is accepted for publication, a separate transfer-of-copyright form must be signed and submitted as a PDF or TIFF file, by ordinary mail, or by fax no later than the deadline for submission of camera-ready manuscripts. It is the obligation of the author(s) to obtain written permission for quotations from unpublished material, for all quotations in excess of 250 words in one extract or 500 words in total from any work still in copyright, and for the reprinting of illustrations or tables from unpublished or copyrighted material.