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The Onboard Context-Sensitive Information System for Commercial Aircraft

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Pilots currently use paper-based documentation and electronic tools, e.g., Electronic Centralized Aircraft Monitoring (ECAM) for Airbus and Engine Indication and Crew Alerting System (EICAS) for Boeing to help pilots performing procedures to ensure increased safety on commercial aircrafts. Management of interconnections using paper-based operational documents can be challenging for pilots, e.g., when time pressure is high and/or in abnormal and emergency situations. This paper presents a human-centered designed tablet-based system, the Onboard Context-Sensitive Information System (OCSIS), which is based on context models improving relevant operational information access either automatically or on demand.

Keywords: Operational Documentation, Information Systems, Human-Centered Design, Context, Commercial Aircraft, Avionics, Tangible Interactive Systems.

1. Introduction

In civil aviation industry, flight crews follow Standard Operating Procedures (SOPs) to complete tasks and ensure safety. In abnormal situations such as a malfunction of an aircraft system or extreme weather conditions, abnormal procedures have to be used for trouble-shooting. Aviation regulations require that each flight crew's action be based on onboard operational documents, which contain procedures, checklists, various kinds of charts and performance parameters. Operational documentation is permanently improved using experience feedback for normal, abnormal and emergency situations. There are four categories of onboard documents: flying documents which are related to all flight operations; systems documents which include systems' theory, principles and controls; navigation documents which are the charts that pilots use on the flight deck; and performance documents which provide operational data for all flight phases such as takeoff, landing and go-around (Tan, 2014).

Pilots are familiar with paper-based manuals, which are easy to use, tag, mark and retain, even if they are heavy and difficult to carry. Nobody can permanently remember all procedures and technical knowledge, under time pressure in particular. Therefore, several instruments, panels and displays have been developed and improved to assist flight crew to support tasks and actions execution. Airbus's Electronic Centralized Aircraft Monitoring (ECAM) and Boeing's Engine Indication and Crew Alerting System (EICAS) were among the first types of onboard information system directly connected to flight parameters. They were developed during the mid-eighties taking into account basic parameters for supporting failure detection and recovery. They have been proved to be extremely useful for providing very comprehensive information on the state of the aircraft in an integrated way, as opposed to previous flight decks where pilots had to constantly check a large number of instruments.

However, these systems did not cover all possible cases. This is why onboard paper-based documentation is still required. The aeronautical community is currently working on transferring related information from paper to computer support (e.g., Airbus's Onboard Information System and Boeing's Electronic Flight Bags). These new tools cover aircraft technical information, operating manuals, performance calculations and mission management information. They are context-free databases. However, computer support enables interconnectivity among relevant pieces of information (i.e., hypertext links) and between cockpit information and flight parameters (i.e., context-sensitivity).

This paper presents a new system, the Onboard Context-Sensitive Information System (OCSIS), which is available on a tablet wirelessly connected to relevant cockpit parameters. OCSIS enables and requires new information formatting (e.g., the concept of page is no longer relevant). In addition, OCSIS's internal information is structured with respect to context. We carried out the first set of formative evaluations including cognitive walkthrough, as well as workload and situation awareness (SA) assessments.

2. Methodology

2.1 Human-Centered Design approach: modeling, simulation and integration

For the last ten years, modeling and simulation technology enables realistic human-in-the-loop simulations (HITLS) early on during the design phase and provision of meaningful and useful user-centered feedback based on human factors assessments (e.g., situation awareness, workload) and users's comments (Figure 1). Consequently, Human-Centered Design (HCD) has been used to incrementally improve OCSIS toward an acceptable mature version (i.e., incremental prototype development, test and modification). A scenario was developed as a sequence of normal and abnormal situations: (1) Fuel Leak; (2) Descent; (3) Approach; (4) Flaps Locked; (5) Landing. These scenarios were used in HITLS with professional pilots for OCSIS tests. HITLS were performed on a fully functional Airbus 320 aircraft simulator at HCDi (Figure 2). This was the first step of OCSIS's scenario-based design (Rosson & Carroll, 2009).

2.2 Context-Sensitive approach: Interaction Blocks

OCSIS's software was developed using a high-level procedural knowledge representation, called interactive blocks or iBlocks (Boy, 1998). Figure 3a shows the structure of an iBlock: it includes a set of actions, a situation pattern (triggering conditions + context pattern) and post conditions (goal + abnormal situations).

Taking the Flaps Set procedure during the approach phase (Figure 3b) as an example, the triggering preconditions are Flaps position (visible on the E/WD screen) and Flaps handle position (visible on the Flaps handle itself). When the Flaps position indicates the same value as the Flaps handle position, then the goal is reached, otherwise, OCSIS informs the pilot that there is an abnormal situation and Flaps Locked abnormal procedure must be executed. Each procedure can be represented, implemented and handled using iBlocks. Consequently, operational procedures can be represented as a meaningful hyperlinked structure.

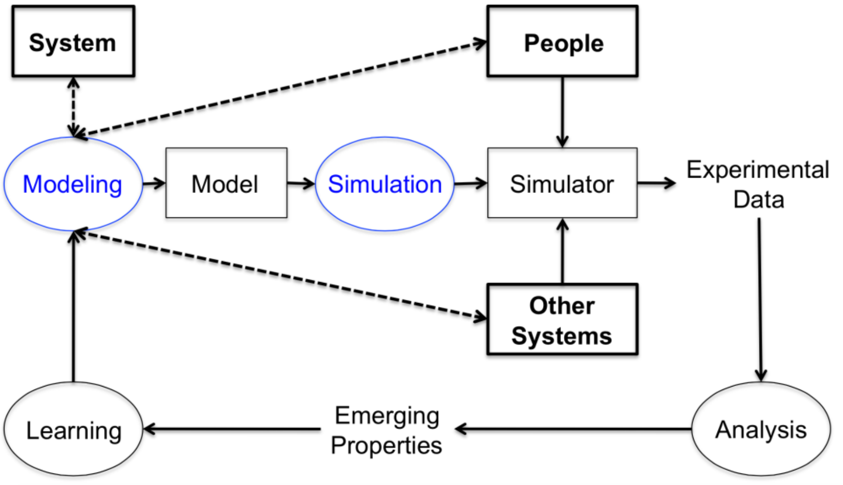


Figure 1: Human-Centered Design approach (Boy, 2014).

Figure 2: HCDi's Airbus 320 simulator.

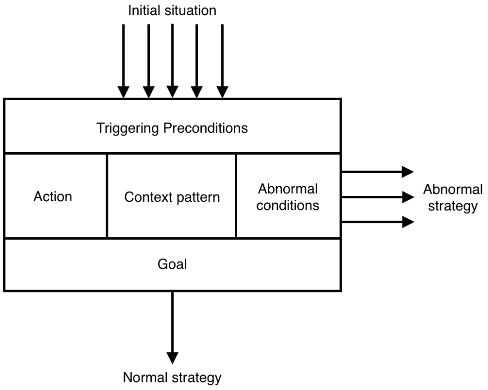


Figure 3a: Structure of an iBlock.

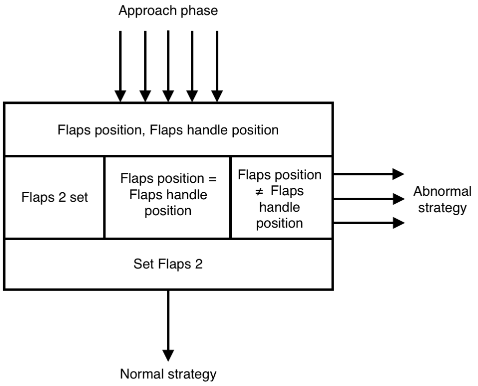


Figure 3b: Application to the Flaps Set procedure.

3. OCSIS prototype

OCSIS's software was implemented on an iPad. It includes three types of operational information for flight, performance and navigation. It is context-sensitive with the purpose of improving safety, comfort and efficiency in normal, abnormal and emergency situations.

3.1 iPad-Simulator synchronization

OCSIS design is based on the claim that context-sensitivity improves pilot's situation awareness, decision making and action taking. This context-sensitivity requires an appropriate synchronization of aircraft parameters with the iPad in real time. Synchronization is performed in three steps: retrieving flight parameters from the simulator, storing them and displaying them on the iPad.

HCDi A320 aircraft simulator is based on Prepare3d, a Lockheed Martin simulation software, which supports the control of various kinds of vehicles (e.g., marine, terrestrial, air or space). It is based on a fully functional aircraft database and provides a realistic flight environment for professional flight crews. Typically, these parameters are retrieved through SimConnect, a library compatible with Prepar3d and then they are stored as an XML file.

Flight parameters were transferred from the simulator to the iPad synchronously using a simple File Transfer Protocol at a sampling time period of 500 milliseconds.

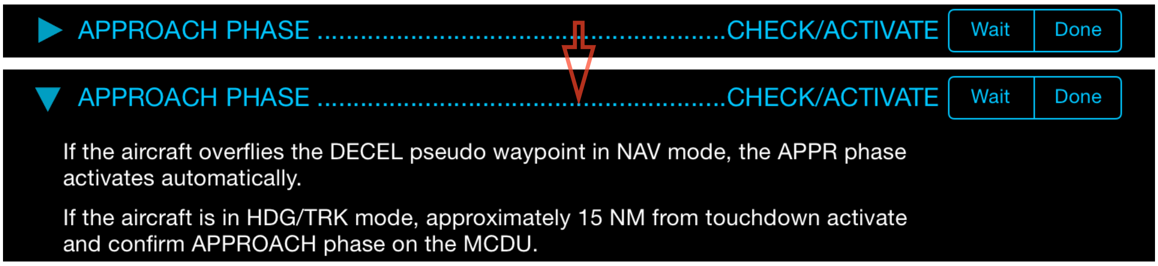
3.3 OCSIS features

In principle, OCSIS includes severals parts: Procedures, Maps, Performance Charts, Flight Plan, Weather information, Manuals, Flight Blog, and Contact Information. Current prototype is limited to Procedures, that are the most important OCSIS part supporting pilots' work support in the cockpit.

Therefore, OCSIS is currently organized into three layers: (Level 1) need to know or safety-critical information that pilots need to have immediately; (Level 2) nice to know or short explanations of Level 1; and (Level 3) technical knowledge on systems principles and trouble-shooting (Blomberg, Boy & Speyer, 2000). A set of targeted normal, abnormal and emergency procedures was developed and implemented. For example, a pilot goes from Level 1 to Level 2 when he/she needs to know more about an action (i.e., selecting the action line leads to more explanation) (Figure 4).

In addition, two main features are presented in this paper: the Dynamic Color System (DCS) and the context-sensitive alert information system. Main purpose of these features is enhancing situation awareness. DCS is shown in Figure 5: Cyan denotes actions to be taken by the pilots; Amber denotes postponed actions or checks; and Green denotes completed actions.

Implemented context patterns trigger real-time procedures in normal and abnormal situations. OCSIS-aircraft synchronization enables the visualization of pilot's physical actions, which is a very important feedback to flight crews. Taking the Parking Brake procedure as an example, once the pilot releases it to OFF for taxiing, the OCSIS can detect the change of Parking Brake's status, and then the related action line turns to Green automatically. In an abnormal situation such as Flaps Locked, OCSIS will immediately inform the pilot about this malfunction by displaying a pop-up information window (Figure 6). The flight crew is then aware of the problem and can follow the ECAM actions; consequently, they can decide to execute the additional related procedures at once or later using OCSIS. If they choose to do it later, a reminder line will be displayed at the bottom of OCSIS, which can direct to additional Flap Locked procedures (Figure 7).

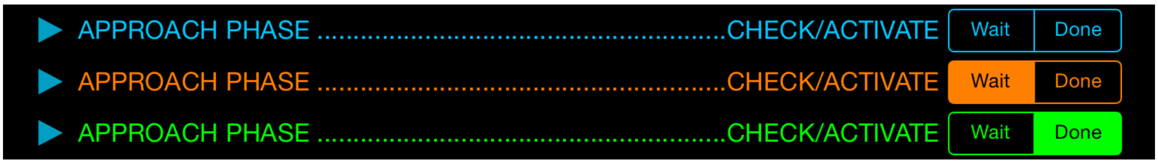

APPROACH PHASE ....CHECK/ACTIVATE

APPROACH PHASE ....CHECK/ACTIVATE

If the aircraft overflies the DECEL pseudo waypoint in NAV mode, the APPR phase activates automatically.

If the aircraft is in HDG/TRK mode, approximately 15 NM from touchdown activate and confirm APPROACH phase on the MCDU.

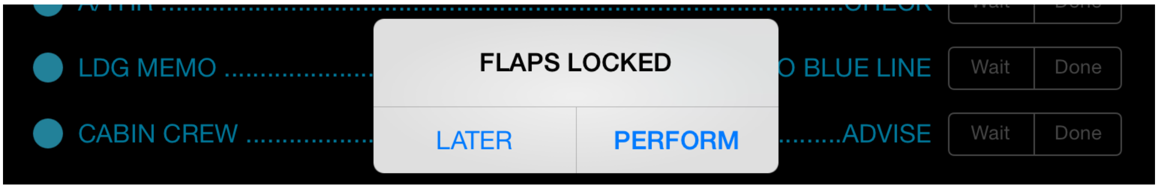
Figure 4: Information needs for flight operations : level 1.


APPROACH PHASE ....CHECK/ACTIVATE

APPROACH PHASE ....CHECK/ACTIVATE

APPROACH PHASE ....CHECK/ACTIVATE

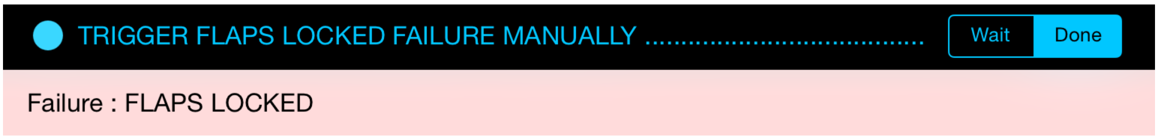
Figure 5: Dynamic System Color.


LDG MEMO .... O BLUE LINE

CABIN CREW ....ADVISE

FLAPS LOCKED

Figure 6: Abnormal situation triggering.


TRIGGER FLAPS LOCKED FAILURE MANUALLY ....

Failure : FLAPS LOCKED

Figure 7: Abnormal situation reminder.

4. Experiments

4.1 Preparation

OCSIS tests include two parts: (1) usability and usefulness tests, which consist in getting feedback from pilots and checking the capability of OCSIS to assist them in their cockpit work; (2) location test, which consist in finding the best location for OCSIS. Pilots with flight experience were chosen as flight test participants. They were required to come twice for two sessions. During the first session, they were asked to follow paper-based procedures. During the second session, they had to use OCSIS. These two sessions were a few days apart for each participant. A briefing was held before each experiment including training, questionnaires and survey.

All participants performed as Pilot Not Flying (PNF) in each test and were requested to perform the following scenarios: (1) Climb, where participants could read and get used to instruments, flight parameters, system parameters, and panels; (2) Fuel Leak, where a fuel leak was triggered around 13,000 feet, which required crew landing as soon as possible and performing related procedures – a survey was generated after the Fuel Leak procedure to get feedback, reviews and self-assessment; (3) Approach preparation, where the Pilot Flying (PF) was in charge of the Flight Management System (FMS) input, briefing for approach and other procedures – consequently, the crew finished the Approach Checklist; (4) Flaps Locked, where a Flaps Locked event was triggered when Flaps 2 was released during approach.

4.2 Experimental protocol

Our experiments, using questionnaires and surveys, were divided into two parts: in the briefing room and in the cockpit (Figure 8).

In the briefing room, for the paper-based documentation test, participants were submitted general knowledge questionnaires and trained to perform normal and abnormal procedures. Then, participants took a Cognitive Walkthrough test (Lewis, Polson, Wharton & Rieman, 1990) to check their understanding of the system. For the OCSIS test, another Cognitive Walkthrough test was conducted to find out difficulties in using OCSIS. Consequently, deeper training on OCSIS was administrated. Finally, pilots generated a usability survey.

In the cockpit, the experiment was paused after the fuel Leak malfunction test; and then participants generated workload and situation awareness surveys. Pilots generated the same survey after the Flaps Locked malfunction scenario. At the end of the experiment, pilots were asked to provide their opinions on the best location of OCSIS.

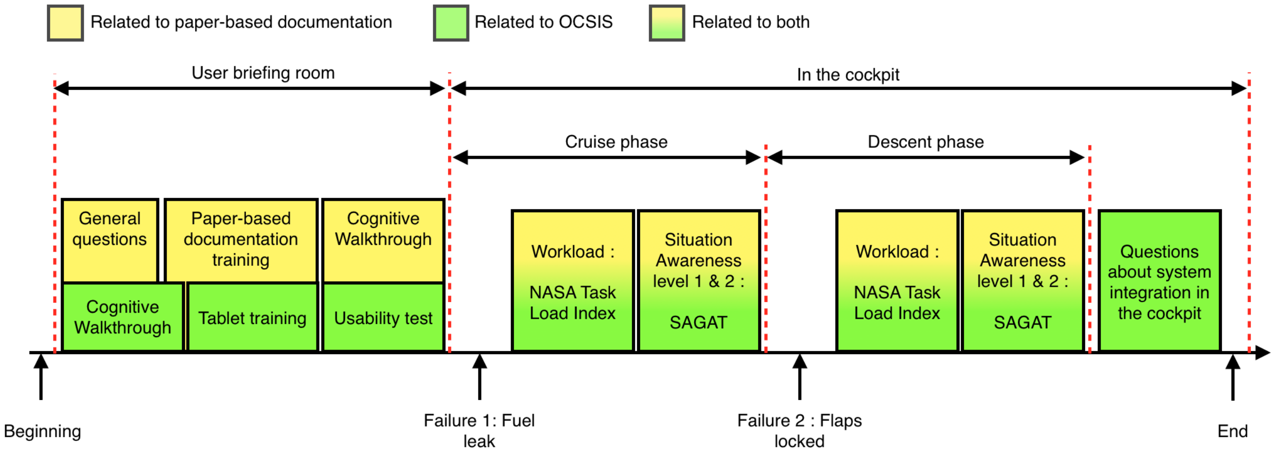


Figure 8: Experiment timeline.

5. Results

5.1 Usability (user-system interaction)

OCSIS was designed following Human-Centered Design principles that promote prototyping for eliciting user feedback during the design phase to discover affordances, design flaws, and reformulate purposes. Cognitive Walkthrough enabled us to assess OCSIS usability. It was based on the execution of seven actions, taken without training. Unlike classical academic studies that involve a number of students to satisfy statistical criteria, our first evaluation involved four experienced pilots. In HCD and more specifically formative evaluations, we privilege expertise and experience to statistics for efficiency and effectivity purposes. Summative evaluations and certification will involve quantitative statistically-relevant studies. Results show that pilots can refer to necessary information when they understand the commands. They can read actions and procedures for different flight phases, understand the DCS and use it. Even if we need to increase the affordance of the title of each flight phase and the text that results from its selection, pilots understood all functions after a short training.

5.2 User-centered assessment methods

5.2.1 Workload

Pilot's workload was assessed after each malfunction during the two tests. We used NASA-TLX (Hart & Staveland, 1988) augmented with an additional visual demand criterion (Stephane, 2013). Pilots' workload was reduced for each malfunction when they used OCSIS (Figure 9).

5.2.2 Situation Awareness

We used the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995). We only focused on perception and comprehension levels. At the perception level, SA assessments were performed using a scale from 0 (bad) to 10 (very good); the average score was 9.45. At the comprehension level, information retrieval ability, action understanding and possible related failure on the ECAM/OCSIS were tested. Only one of the four pilots could not understand a few actions, but all others were positive, showing that OCSIS can provide the right information at the right time. DCS was also assessed by the participants using the same subjective scale; the average score was 9.3.

5.3 System integration in the cockpit

During the debriefing, all participants were requested to give their opinions about where OCSIS should be located in the cockpit, and if it should be fixed or moveable. Figure 10 presents the suggested locations according to the pilots. Four positions have been pointed: (1) near side-stick; (2) on a flexible arm; (3) in a sleeve near the seat easy to handle; or (4) on the pedestal or instrument panel as a unit.

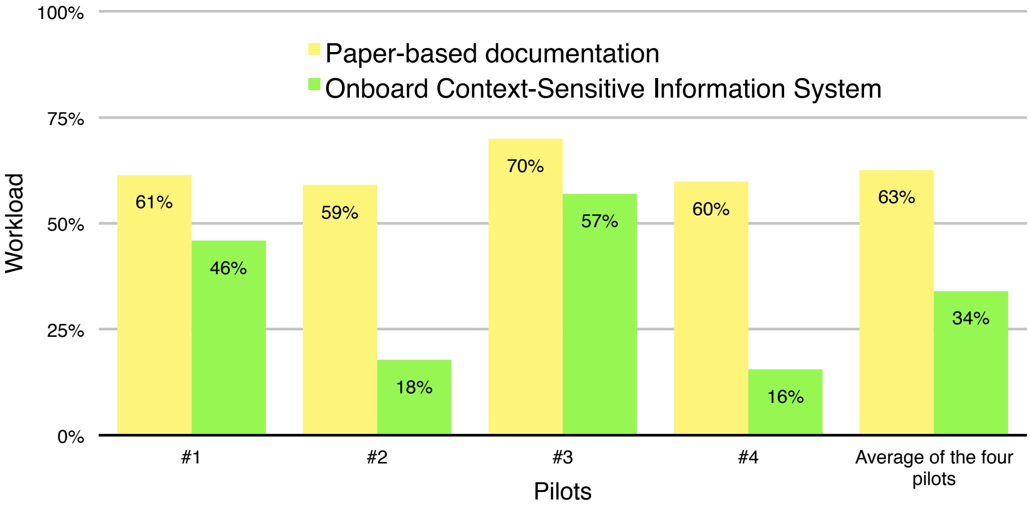


Figure 9: Average workload per pilot.

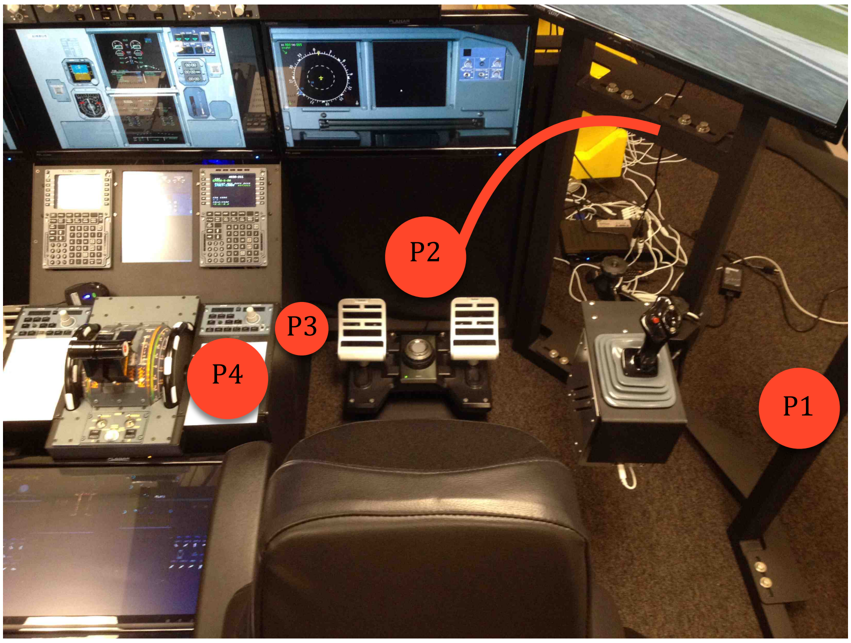


Figure 10: Different suggested positions for the OCSIS in the cockpit.

6. Discussion: An iterative design process

OCSIS was first designed as a piece of software that had to be later on used as a tangible interactive system (TIS) onboard commercial aircraft. The main issue we had to solve was tangibility. Indeed, onboard paper-based documentation is being used since the beginning of aviation and is tangible for pilots (i.e., natural to grasp, handle and use). Tablets are now commonly used by a general public including pilots. Consequently, we considered that tablets are tangible objects that can support OCSIS software. The first experiments that were carried out showed that this hypothesis was confirmed on a fully equipped cockpit simulator in flight operations with professional pilots. Of course, more iteration needs to be implemented to get a mature OCSIS.

This paper provides a first iteration of a participatory design of OCSIS. More generally, it shows the shift from the traditional automation approach where more software was added into the cockpit and induced some kinds of rigidity that sometimes results into surprises, to TIS design where tangibility has to be tested against flexibility criteria. (1) DCS provides dynamic SA that increases flexibility on pilots' actions (e.g., when a do-list action is not possible to execute yet, the amber color reminds the pilots for later execution). (2) Using OCSIS pilots can decide to postpone an abnormal procedure and the system is able to remind them at an appropriate time. (3) Using OCSIS pilots have direct access to the first layer of operational information and to the other layers on demand (i.e., providing a great deal of flexibility). (4) Global checks are possible, which improve flexibility in a high time-pressure situation. (5) OCSIS connectivity with flight parameters provides useful affordances. (6) OCSIS knows about pilots' actions on cockpit instruments and provides redundant feedback (i.e., this additional cross-checking support is very useful for safety and efficiency purposes).

7. Conclusion

Context-sensitivity in operational procedure following is a new feature that electronic media enables providing more flexibility in an aircraft cockpit. The main problem in this approach is the definition of context patterns because when a context pattern matches the current situation, it triggers an appropriate procedure. Therefore, context patterns have to be discriminating to propose the right procedure to the pilot. For example, in the After Engine Shut Down event, the system has to know if the aircraft is on the ground or in the air in order to propose the appropriate procedure. It is clear that context pattern definition is a complex problem, but current OCSIS design and positive test results encourage us to pursue this context-sensitivity approach. We plan on developing an extensive context identification effort in the next phase of this project.

Human-Centered Design is about creativity and evaluation. Creativity is integration of existing things. In OCSIS case, we integrated very well-known technology and techniques. For example, we integrated on a tablet context-sensitive software and appropriate connectivity with flight simulator. Domain content and technology were realistic and enabled us to involve professional pilots. This led to very credible simulations, which were used to test the OCSIS tangible interactive system. The first formative evaluation showed that OCSIS provides much safer, efficient, and comfortable operations in the cockpit. We are aware that this is a preliminary result but it provided input information for an improved design of OCSIS, which we are currently developing.

This work is a first phase of the design and development of OCSIS. It is based on both participatory design and agile development (i.e., at the end of each phase, the system is testable in HITLS environment). This is now typical for the design and development of tangible interactive objects (Boy, 2014), and more generally tangible interactive systems (TISs) (Boy, to appear), where the problem is no longer automation but the search for tangibility. Modeling and simulation is required to explore possibilities and drawbacks of these TISs. The quality of both simulation capabilities and pilot participants is crucial.

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