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ABSTRACT

In order to contribute to a design for future airline cockpits that can address the limitations of touch-based interfaces, we analyze tangible dimensions of cockpit activity based on observations and pilot interviews. Working from these data, using TEI theory and concepts of phenomenology, we discuss the implications for tangible design of our findings. We found that the status of sensation in perception, the required level of control in actions, the safety issues using physical objects and the restricted mode of externalization, raise challenges for tangible design. Accordingly, we discuss key concepts for the design of the future cockpit, such as the use of a protected space where interaction may involve compressed externalization, rhythmic structures and customized context-aware adaptations.

Author Keywords

Tangible interaction; physical skills; time-based interaction; design; ethnography; phenomenology; aeronautics.

ACM Classification Keywords

• **Human-centered computing~Human computer interaction (HCI)** • Human-centered computing~HCI design and evaluation methods • Human-centered computing~Field studies

INTRODUCTION

Touch technologies are replacing current electronic displays in airline pilot system interfaces. However, while safety and performance require interactive instruments to maximize the perception, action and collaboration spaces offered to pilots, the literature highlights the limits of touch interaction for these aspects [1,5,9,24,30]. Tangible, Embedded and Embodied Interaction (TEI) frameworks and themes [28,42,48,62,70] appeared to be a promising means to address these limitations and might help frame useful directions [68], while also raising certain issues. Firstly, TEI focuses on the materiality of the interface, the physical embodiment of data, and physical objects as representation and control for digital information. It may also involve whole-body interaction, or the embedding of the interface and user interaction with physical objects in real spaces. The first type of issue concerning these themes and concepts is only technical: there are safety constraints that prevent the use of physical objects, and bodily movements are restricted. Additionally, this raises the question whether technically "adding" physicality is the sole valid design approach.

Another approach [13,14,15,58,65], is to take a broader stance on tangible and embodied interaction as described by Dourish that emphasizes the primacy of practical interaction as a meaningful experience in the world [15]. Exploring this more theoretical standpoint, grounded in phenomenological concepts, helped us to frame an application of TEI themes to the aeronautical field, where a specific experience of body, time and space for pilots involves somewhat modified perception habits.

In this paper, working from our observations and interviews, and using tangible interaction theory and its phenomenological conceptual apparatus [15,63,64,49,26,17], we try to understand what interaction is for pilots, and the implications for design that can be drawn from this understanding. We form hypotheses, based on their utterances, on what it means precisely for pilots to "be in the world" as "lived bodies". We then frame what this implies for the design of the future interactive cockpit. We discuss a set of challenges for tangible design such as the use of haptics, rich representations, physical objects, sensor-based design or space-based externalizations. We propose a set of key concepts, such as compressed externalization, customized context-aware interaction, rhythmic structures and a protected space of interaction.

After describing the context of the study and the methods we applied, we provide key observations on themes that emerged as relevant for the framing of tangible interaction in the airliner cockpit. Then we propose an interpretation of our findings about perception and action using phenomenological concepts. Finally, we discuss tangible design perspectives for the cockpit of the future as informed by our key observations and interpretation.

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RELATED WORK

In a context of significant changes in pilot-system interfaces, research on cockpit design addresses human factors issues [59] on complexity (workload and errors involved in concurrent tasks) [45], human-centered or adaptive automation [6,60,36,11,39], and new interaction paradigms. [4,55,38,40,5,8]. Closer to our approach, ethnographic studies describe pilots activity. Hutchins et al. study distributed cognition in the activity [34,32] and how speech and gestures combine to build a coherent interaction, and Nomura et al. analyze the use of paper in the cockpit [52].

In addition to these lines of research, this work also draws on tangible interaction research using phenomenology to frame embodied dimensions of being-in-the world, i.e. where interaction finds its meaning and value in given situations within the physical and social world [15]. It also relates to embodiment as used for the analysis of interactions in collaboration when people are co-located [27,58], where the term "embodied action" is then used to name the publicly available, meaningful actions, such as talking, touching, drawing, or moving around. Studying embodied interaction may also help to establish an understanding of how computing is intertwined with human users and the world [18] and to investigate the active role of the body as a present-at-hand tool [54]. This work finally relies on tangible interaction themes as a design space to be explored, in particular regarding the perceptual-motor-centered concerns, looking more closely at bodily interaction with objects, sensory richness and action potential together with space-centered views discussing the combination and architecture of real space with virtual displays [28].

CONTEXT

Airliner cockpit: a specific workspace

An airliner is typically operated by a crew of two pilots; one, the Pilot-In-Command (PIC), is the captain, while the other is the supporting First Officer (FO). Furthermore, at any time during the flight, the pilots may perform two roles and associated tasks. The Pilot Flying (PF) is the pilot in control of the flight trajectory and the Pilot Monitoring (PM) is responsible for monitoring the current and projected flight path, the energy and the system states of the aircraft. The air crew ensure the security and safety, the smooth running of the flight to the destination airport and the comfort of the passengers. On commercial flights, pilots collaboratively perform five major activities: aircraft piloting (most often with autopilot), navigation (managing and tracking the flight route), aircraft system monitoring, communication with air-traffic controllers and ground support, and accomplishment of the company mission.

Cockpit ergonomics: posture, perception and gestures

To conduct these activities, pilots interact with the aircraft systems through specialized interfaces on the flight deck. The two pilots seat side by side, in front of the dashboard and facing outside. The flight crew seats are electrically and manually adjustable; however, each pilot ultimately remains in a fixed position, strapped on their seat and inserted under the dash. This position enables him/her to lean toward the dash or turn toward another crew member, but ultimately restricts their actions to the attributed controls. The seat height is adjusted to ensure that the operator's eyes are exactly aligned with the standard point of visual fixation, accessing equally the inside and the outside of the aircraft.

Toward the digitalization of pilot-system interfaces

In the 1980s, the Glass Cockpit concept radically changed the flight deck interfaces of commercial aircraft, replacing dozens of analog mechanical instruments by a digital display of the aircraft system information. The data are grouped into functional units and displayed on specialized screens, dedicated to each of the crew's main activities. The crew interacts with these systems and data through physical controllers: knobs, switches, pull buttons or sticks. These finely tuned physical control devices have proven their effectiveness for pilot-system interaction, situational awareness and cooperative work, even in degraded contexts of use, such as poor flight conditions, instability, degraded vision (smoke), pilot fatigue, high cognitive load or stress.

Touch-based cockpit: a new challenge for aeronautics

The increasing complexity of aircraft systems leads to a more integrative approach with an aggregation of cockpit systems. In particular, the continuous increase in data and functions available for pilots requires more flexible information display and interactions, that have been recently proposed using touch screens [71,24,40,5]. Versatile designs may be used in a variety of civil and military avionics platforms, and allow manufacturers to build powerful, flexible and innovative product lines for the cockpit at a lower cost. The new touch-based interfaces have many advantages: direct interaction on data, multitouch gestures, shared access, adaptivity to the flight context and easier maintenance. Nevertheless, tactile interaction results in reduced mutual awareness and has severe limitations in critical contexts. Unlike physical controls, which benefit from the sense of touch and proprioception, such interactive screens are unsuited for eyes-free interaction, do not favor mutual awareness and crew collaboration, and are unreliable in dynamic environments subject to vibrations and acceleration [1,69,5,8,9,68]. Yet, in the context of air safety, life-critical systems demand reliability both in normal and degraded operational situations.

The Airtius project

Funded by the French research agency and an aeronautical industry research consortium, the aim of the Airtius project is to contribute to the evolution of airliner cockpits while guaranteeing air safety. Its technical objective is to explore a mixed interactive approach for safety-critical contexts, based on both touchscreens and physical components (deformable surface, emerging part, physical feedback, connected object) to ensure greater consideration of sensory motor skills and enable more effective crew collaboration. A first step of this project resulted in a structured design space for pilot-system interactions, classifying the design properties of physical interaction depending on relevant usability, safety and industrial requirements [68].

STUDY

The study is based on observations, interviews and participatory workshops organized with 8 airline pilots. Previous project data and observations involving more than 30 pilots were also used as a basis for understanding the activity [10,67,44]. Observations were run either in flight or in airliner simulators. They were all videotaped (5 hours of video), and partially transcribed. Around 20 hours of contextual interviews were conducted, linked to simulator sessions or workshops. They were first transcribed (~ 450 pages) then around 260 quotes were extracted. During 6 workshops, pilots were invited to contribute to reflection, either by providing feedback on preliminary prototypes or design drawings, or by participating in brainstorming and prototyping activities. Quite often, contextual interviews were informally conducted during workshops, letting a pilot report on a recent situation which s/he recalled, triggered by an aspect explored during the session.

As a first analysis step that was aimed at gaining a closer and shared knowledge of the data, the quotes extracted from the transcriptions were classified in a relational database into main topics and subtopics, using an online web application to share data. Topics were selected through an open coding approach, coming either from the activity (safety, cognitive load, monitoring, situational awareness, decision), or from the project focus on tangible interaction (action-perception, shape, space, gestures) or also as emerging topics, such as rhythm, speech or control. Based on this first classification step, we were able to highlight a set of key characteristics that we analyze in the next sections. We also held 10 design meetings where we related key observed characteristics and tangible design questions. Finally, design explorations and tool implementations were made through five 1-month and two 3-months student projects, most of them also involving pilots and performed by students in aeronautics.

KEY OBSERVED CHARACTERISTICS

The insights we have gained from this study[1] are as follows.

I. Status of sensations and body

We observed the characteristics of embodiment in airliner pilot actions and decisions. We distinguish two types of situation: situations where the pilot is in a monitoring role or in a phase of the flight where time is available, which typically occurs during cruise (*I.a,I.d,I.f*); and secondly, situations with a high demand on active piloting and real-time actions (*I.e,I.g*). These two types of situation may be intertwined, and are often distributed among PF and PM.

I.a) Indirect instrumented perceptions. The airliner pilots highlight the air safety requirement to always rely on indirect perception through instruments (this is in contrast to VFR pilots). Proprioception or visual perception looking out from the window is potentially illusory [21], and, as one pilot explained: *"You mustn't believe your sensations, you may experience an illusion, believe your instrument."* (1). Pilots are even more confident in exact, digital information abstractly provided on their displays, such as a numerical value, rather than a synthetic visual representation. One pilot said that *"a representation of relief is an improvement but you still need to check your security altitudes."* (2). The only sense that pilots seem to trust is the tactile sense, that enables them to differentiate controls or buttons through their form (Figure 1), as one of them commented: *"you know that the button with larger notches is the speed"* (3).

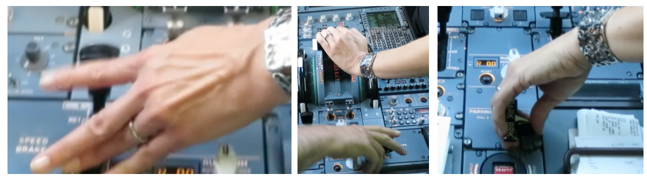

Figure 1. Using the form properties of the physical controls: a) flap; b) throttle; c) parking break.

I.b) Body considered as technical. Pilots may describe their body in a technical way, for instance explaining that it is not provided with sensors, as in this description of landing: "*Landing is still a kinesthetic phase. We don't have sensors that give us the sensations of the plane, our sensors are ourselves. So, how are we going to feel this plane?"* (4). In another example, a pilot uses the metaphor of a sensor that would inform of the other pilot's nervousness with their hand on the stick: *"As we don't have an instrument to tell us about 'the other pilot's stick activity', you have to look"* (5).

I.c) Reluctance towards body-based interaction. During participatory design workshops, we noted that pilots were reticent towards ideas involving interaction through their own body, such as palm-based interaction [23]. One of them explained that when in a degraded context, for instance under stress, you cannot anticipate how the body would react, explaining for instance that palm-based interaction would be impossible if the pilot clenched his hands.

I.d) Gestures for perception. Perception of information is described by a pilot through actions and gestures to reach and catch the data, sometimes within a rhythmic cycle of fast operations, as illustrated by this quote: *"In fact when we say that we 'are looking' ... we know what we are looking for* […] *you go and take the information you need, you put it in your head, you come back to your instruments."* (6), where the pilot explained that they capture the information, rather than look at it, illustrating their explanation with a repeated grasping gesture. About scanning the instruments a pilot said: *"muscular with the eyes, it won't be enough"*. They need to touch the displays and controls*:* "*we'll go like this; we'll touch the panel, there, there, that's like that"* (7).

I.e) Sensations needed for piloting actions. In contrast with abstract perception, concrete sensations are put forward in actions involving intense control, where pilots need to feel their movements and their body. In such situations, as one pilot described, they need to *"be one with the plane"* (8), to *"feel"* it

[1] Quotes are referred to by an ID, their full text (original and translated) is available as an auxiliary file.

(4). One pilot described such a situation: *"We had a real sensation of control* [grasping gesture with the left hand]*, all the senses were … adapted …* [hands clasped] *to the plane… what was going on outside was represented by the action on the stick* [activating the stick]*… and there's a correlation between what you see* [points] *what you feel* [right hand fingers tight on his leg] *and what you act on* [right hand indicates left hand]*"* (9). This pilot explains: *"when you say sensation: it is an effort on the stick, it is muscular"* (10). It has to be noted that this highlighting of sensation occurs in control loops where the pilot suffers the situation and follows the plane, where actions are not entirely voluntary. Landing is the phase with the least control: *"the last second before impact… before touchdown* […] *you can't control it any more… you can feel whether it'll go well or not."* (11). The embodied nature of this situation is underlined as a lack of an objective technical sensor: *"there is no instrument that could give us that information at that moment – it's what you experience – the speed of the runway rising* [hits the back of his hand on his palm]*"* (11).

I.f) Sensations optional for voluntary actions. In contrast, actions involving switches or rotary buttons are not considered as requiring sensations, since they are fully controlled: *"it's an objective you give yourself, we'll display something", "it's that we have gone and displayed something on purpose [*makes a gesture towards the instrument with tightened fingers*] it is not something that is done in … how could you say that, in the form of sensations"* (12).

I.g) Role of the eyes. Eyes play a role in physical situation of control: *"'Being one with the plane' as an image means: this plane, you put it where your eyes lead you.* […]*If you decide to land it in a certain place, well, you just have to target the place […] you just have to act, and the plane will go where you placed your eyes."* (13). As explained by Gibson [22], sight targeting a runway in a landing glide builds an optical array that is invariable at the aiming point, and this invariance, created by sight, is similar to the artificial horizon symmetry indicator of the PFD that the pilot has to keep aligned (they call it *"keep the ball centered"*). Here again the body has a technical role similar to that of an instrument.

II. Externalization and speech

Oral communication in pilot activity is primordial and has been already widely studied (e.g [50, 33], to cite a few). We are only interested here in properties of oral communication between pilots that we feel are relevant for tangible design. Almost all interaction involving collaborative decisions or collaboration design (mutual and situational awareness, etc.) is based on verbal communication, as a formalized (and recorded) yet flexible tool. Speech has also a significant connection with temporal structures, as we describe later.

II.a) Oral communication as externalization. During interviews, pilots repeatedly use verbs denoting speech: they explain that they "say", "tell", "report" something. For instance, instead of simply describing actions while tuning a parameter (such as speed), they state: *"He **says** 'speed'. The other pilot **replies**: ' I'm correcting that.' "* (14). This highlights how pilots need to bring their representations into a shared and perceptible space, externalizing their thoughts in a way quite similar to Air Traffic Controllers using paper strips to collaborate [46]. Speech has a display role, in the absence of a central shared area in current cockpits, as illustrated by the comment from a pilot: *"you cannot trust the other pilot, who **says** he has got the proper folder hierarchy"* (15), although speech may miss important aspects *"we are each on our own side, we each have an EFB and when the other pilot, for example, wants to describe a trajectory we lack some visual elements"* (16). This display role is enforced through the use of narrative forms. Indeed, reporting about the way they collaborate, pilots sometimes almost equate a briefing to a story that is told: *"the briefing during which you **tell** how you see the situation, you **tell** how we have understood everything, and what we are going to do"* (17). As a result of this display role, similar to the one of a screen, oral communication is also a means for cross-checking (as a matter of fact, ATCo do not rely so heavily on oral communication. Except for inter-sector or inter-center communications they might not need to, since they know each other very well, as opposed to pilots).

II.b) Utterances as control actions, while independent from the system. Oral communication has a primary active role during the flight, but unfolds without any connection to the aircraft systems (at least to a certain extent since it is recorded). Decisions also occur through oral communication, which pilots describe as *"one to one"* communication (18), meaning that it is a task that is disconnected from the systems, yet a structured one. In briefings, an action plan is turned into an oral encoding that stands for itself and should not be interrupted. Doubtful aspects should be dealt with beforehand. *"When you're ready for the briefing, you are ready and it's all set.* […] *and you are not going to say stop, because at the end of the day, a briefing is something that's almost held sacred , as it's our action plan."* (19). Switching the roles from PF to PM and the reverse merely involves an utterance, such as: *"my control, your ATC"* and utterances have a role in procedures, e.g : *"The fact of saying 'flaps' in the checklist 'after start' triggers a change in the items of ' before take-off ' checklist"* (20). Oral communication also has a validation role, too, with statements such as *"gear down"* (21), as a valid display of the state of the system.

III. Embodied temporal and rhythmic structures

As demonstrated by Gibson [22], there is nothing such as abstract time, but rather the perception of a succession of events, moves or changes. Therefore time is perceived through its effects starting with, in the case of a flight, continuous changes in location. Obviously, activity is shaped by the duration and phases of the flight and by concerns related to time, while expressed in various units: this is the case for fuel, distance and speed. Finally, many pilot tasks are constrained by synchronization and real-time events.

III.a) Rhythms as an embodied resource. A prominent temporal aspect that we were able to note was that pilot activity is structured through rhythms. This is not only through temporal patterns repeated over time, as in many collaborative and time dependent activities [57], but also as an embodied resource and capacity, through speech or gestures. This helps to support various tasks, such as visual scanning to check instruments through a predetermined path. The repetition of *"we* *touch"* in the following quote, underlined with bodily touch gestures says something about these embodied rhythms: *"In fact, we touch when we go on the throttle […] we go and to touch… we go like this, like this… we go and touch… it's like this, like this… we touch… you see it's* ***like a sort of music"*** (7). Together with this rhythmic sequence the pilot underlined the embodied nature of the task, explaining that scanning is not only visual, but also tactile, tactile being more muscular than the use of the eyes only. The sequence is also compared to music, i.e. something that you learn by heart, ensuring some physical automation to obtain a safe and exhaustive check. We indeed noticed several associations of *rhythms* and *monitoring* tasks, illustrating that rhythms, as embodied routines, are a resource to support pilot work. Highlighting its rhythmic structure, a pilot also compared the briefing to a ***"chronology",*** i.e. a temporal structure where elements are arranged in the order of time and with a given pace: *"well we build that chronology as we go through the charts"* (22). A rhythmic structure is also observable, using repetitions and associated with speech (*"you talk"*), in this description using a spatial metaphor comparing the arrival sequence to a physical thread: *"it's as if we unwound a thread from where we are to where we're going… so we talk about the descent, we talk about the approach, we talk about the final…"* (23).

III.b) Collaborative synchronization patterns. Rhythms and temporal structures also help in synchronizing collaboration [51,57]. Pilots have an embodied knowledge of task durations, and as the tasks are organized in a linear way, they know when they will be able to cross-check and resynchronize each other: *"You've got your flight path, the runway in use is that long, so I have to take-off with so much thrust and such a flap setting. So it all goes together in fact, therefore you can imagine that in any case we will have to cross-check the other pilot's task."* (24). Pilots first need to perform independent parallel individual tasks, afterwards, they are able to share, synchronize, and cross-check, because "[they] *have to remain independent,* [they] *cannot rely on the other pilot only."* (15).

IV. Embodied anticipation of lacks of time

IV.a) Externalization for anticipation. Spatialization helps to anticipate any lack of time in preparing ready to use action plans. These plans take the form of " control structures " to be instantiated later. In some companies such as Air France, pilots even have control structures at hand, called " FORDEC " for Fact, Options, Decisions, Execution, Control. There are times for preparation actions, too: *"So now it's time for me to tell my copilot that if* […] *we'll* […]*"* (25). However, spatial and temporal resources are also subject to a trade-off: when no time is left, spatialization is no longer possible, resulting in a compressed style of externalization that involves mostly language or gestures.

IV.b) Gestures for anticipation. Anticipation continuously occurs in gestures that may simultaneously perform a task, such as monitoring the throttle (Boeing) and be ready for other ones, such as deictic ones for checks (Figure 2.b).

V. Embodied use of the cockpit space

With training, pilots know precisely the cockpit shape and dimensions, the position of each panel; they are able to automatically locate controls without using their eyes (Figure 2.a): *"These are gestures that are done so often… the amplitude, the position…* [the hands] *fall automatically in the right place."* (26), even more so when commands are grouped logically in subsystems, or when their distance is consistent with the standard position of the pilot's body: *"You know when you are piloting and you look outside, your hand will fall on the weather radar, and you'll be able to set the tilt* [antenna angle] *without looking."* (27).

Figure 2. a) Bodily use of the internal physical space of the cockpit; b) anticipation in gestures.

FRAMING QUESTIONS TOWARDS EMBODIMENT

Prior to drawing implications for designing tangible interactions for airliner cockpits, we need to reflect on how to account for our key observed characteristics, in particular regarding: 1. the status of sensation and body in both perception and action and 2. the level of awareness and control involved in pilots' actions. For this purpose, we attempt in this section to build an interpretation of our findings using theoretical work, to help us rephrase what embodied interaction may mean for airline pilots.

Phenomenological account of perception and action.

During our study, we became aware that pilots experience a dual embodied space, which has a deep impact on perception and action in the cockpit.

The proximal embodied space

The first element is formed by the surrounding internal space of the cockpit. This protected living space can be considered as a bubble, where natural laws apply. Elements such as walls, openings, fittings, instruments, but also pilots or embedded objects, all are part of a continuous, consistent and stable space. Inside this proximal space, perceptual and physical access is direct. It is encoded in the pilot's body by the thorough knowledge of their place of work and by the skills resulting from constantly repeated procedures, postures and gestures: the pilot's hand that automatically falls on the appropriate control, the gesture-gaze coordination that crosses the flight deck or the body-based collaborative work between the air crew members. In this internal space, pilots trust and make full use of their sensations and physical capacities, they can even get up or move if needed. This part of the space where pilots interact shows the usual features and properties of the human physical space, even for degraded contexts where visual or physical access is made difficult by e.g, instability or fire.

The outer strange space

The second part of this dual embodied and perceptive space is the outer of the cockpit. Strapped into their seat at the flight controls, the pilots become an extension of the aircraft itself, like a centaur, projected at high speed through the sky, a "non-human" space. In this unstable egocentric world, landmarks are weaker, less numerous, moving, inaccurate (cf. cloud masses) and without measure. In this outer space, only visual access is available to pilots, at a distance, and, as they experience spatial disorientation very often, pilots tend to distrust their perception.

From abstract perception to extended body

Our analysis of the different status of sensations according to the control situation (*I.a, I.e*) is consistent with this concept of a dual space. Merleau-Ponty's theory of perception [49], as applied for instance in Svanæs work [63,64], may also provide a coherent account of our findings. This view considers perception as active, based on the whole body and intentional. In particular, it provides a concept of the body as not only able to adapt to technical artefacts, but as extending itself through devices. This view is in line with the way airline pilots distance their perceptions. They do not "trust their eyes" to get critical information because they are in fact "blind" when flying at over 600 mph in poor visibility conditions. As a consequence, they perform an active scanning of their instruments, in a manner analogous to ocular movements. Therefore we can refine our analysis: perception is not exactly "indirect" or "abstract" (*I.a*). The PFD being an extension of his sensory apparatus for the airline pilot, perception is adapted rather than indirect, or more exactly *transferred* to instruments.

A distributed bodily space

We also need to account for a contrasting need for "feeling" during real-time piloting phases (*I.f-g*). Taking our reflection one step further and viewing the instruments as an extension of the pilots, could *the plane itself* be considered as *an extension of the pilot's body, as an object modifying their bodily space* [63]? In these phases, being "one with the plane", the pilot needs strong physical feedback with their proprioceptive senses that are tightly coupled with the machine. At the same time, pilots distrust their own perception and give an account of their body in technical terms (*I.b*), so that their "real" body [2] tends to fade (see [54]). This distributed and highly coupled body may also explain why, while research demonstrates that moving one's body increases one's cognitive abilities [61], pilots may be reluctant to the idea of not staying seated, preferring to stay in contact with the equipment.

Maintaining an envelope

The issue of control is constantly present in pilots' work, as shown in many of the characteristics described above. However, it remains difficult to define exactly what control is. Another approach is to look at what control is not, to understand what is removed when things are not under control. It turns out that "not controlling" may result in situations where an envelope [47] of standard, expected or predictable behavior is lost, leading to a situation subject to dispersion or explosion. For pilots the core objective is indeed to maintain the plane in a safe envelope and trajectory to carry passengers safely to a location on the ground. Distance from bodily sensations (*I.a*), visibility of actions and reflections through oral utterances (*II.a*) and physical control in piloting actions (*I.g*) all contribute to this control: they both keep pilots in the loop and provide the tools required for anticipating and taking appropriate decisions.

Level of awareness and intention in actions

We believe that phenomenology again provides an interesting way to account for the manner pilots manage the problem of control, combining two concepts. The first one is the distinction by Heidegger [26] of *ready-at-hand* and *present-at-hand*, as already used in HCI [15,54,64]. The second one is the duality of *abstract / concrete* actions from Merleau-Ponty [49], has used by Svanæs (as an equivalent to *foreground / background* duality [63,54]) to account for context aware systems [63]. These two pairs of concepts are relevant for the issue of control, but *foreground/background* is more related to intention, while *ready-at-hand/present-at-hand* is more related to awareness. Given the constant need to maintain this envelope, the control actions and even perception actions performed by pilots show a high degree of awareness. In particular, anticipation tasks involve a present-at-hand mode, and rely on various externalizations through speech, maps, and notes [52].

At the same time, these highly controlled actions are based on many ready-at-hand skills. Automated actions are, however, considered both as critical resources and a potential threat by pilots: *"Doing actions like a robot can lead to errors"* (20). Automation (Flight Director, Auto-Pilot) is also considered by pilots as a ready-at-hand resource that they are happy to collaborate with when required (low visibility, fatigue). However, automation is also a concern: they have to monitor and adapt to it, which involves a significant cognitive load: *"So you have to adapt to the automatisms. And we see all sorts of things in the cockpit. And we can say that the automatism has been badly thought out, that is doesn't cover all cases."* (28). As described by Dourish [15], there is in fact a "*constant interplay between both levels, a variable coupling* [that] *is so crucial that the effective use of tools inherently involves a continual process of engagement, separation, and re-engagements*". Such interplay is also supported through rhythms (*III.a*) that help stay in the loop, and synchronize and switch between action and control.

Foreground vs background actions refer to intended and abstract actions vs indirect but also concrete actions [49,63]. What is considered as foreground according to Merleau Ponty indeed depends on our focus of attention and our intention and not on the physical action itself. Pilots not only show a significant level of awareness in their actions. They also describe them as voluntary, such as taking information from the instruments (*I.a, I.d, I.f*), except for actions that are suffered, such as landing (*I.e*).

In the next section, one of the issues that we discuss is to what extent ready-at-hand and background control modes raise a challenge for tangible interaction design.

IMPLICATIONS FOR DESIGN

Transposing embodied interaction in the sky context.

As a result of these reflections, we can see that, for pilots, meaningful interaction [15] translates to safe, comfortable, efficient and possibly cost efficient flying in a much adapted environment. The voluntary transposition of the body and perception is adapted to piloting and monitoring needs in the proximal and outer spaces, and to the transition back and forth between the two. Consequently, "being in the sky", pilots have to consider their "distributed bodily space" as a controlled tool or subsystem [54]. Flying therefore involves a specific design for embodiment and interaction, where transferring a significant part of the "being in the world" abilities (perception, body) into artefacts is challenging. Translating Merleau-Ponty's statement that "*The body is our general medium for having a world*." [49, p 146] to being-in-the-sky would thus results in the coupled entity composed of pilot skills and plane subsystems being able to control what has to happen in that world.

Anticipating TEI design for airliner cockpits involves several discussions: 1) pilots expect large improvements from touch-based displays, while knowing their limitations, and " physicalizing " displays raises important *safety issues* [68]; 2) the values of tangible and embodied interaction " in-the-sky ", as described in the previous section, *challenge* the values of TEI " in-the-world "; 3) which are the *key design concepts* that could bring meaningful interaction in the sky context. In the following, we first briefly present the pilot viewpoint on touch-based applications. We then discuss TEI directions informed by our analyses, addressing both design challenges and key concepts.

The pilot viewpoint on touch-based tools

In our study, pilots discussed the trade-offs using touch-based applications against old fashion specialized displays. They believe in their advantages for taking context and system state into account dynamically. They are eager to use electronic checklists appearing at the appropriate time and place, *"checklist that comes up on the ECAM"* (29), rather than having over 50 paper-based and hard to memorize checklists (*"On Boeing we've got an enormous manual."*). Touch-based applications could also prevent paper scattering, as explained by a pilot showing how he would *"hold"* an electronic checklist in place with his hand (30). The same applies for maps, where a single zoomable document would be preferred: *"Because here today at Orly, we have 8 or 9 ground maps, in the end, the very best thing would be just a single large map on which we could zoom in an out."* (32). Globally speaking, touch-based applications tend to be preferred for long-term strategic management actions. In contrast, a "fully digitalized" MCDU (Multifunction Control and Display Unit), or any other short-term tactical controller, would result in a less-integrated tool [3], where no link (causal, mechanical) can be made to what is going to happen: *"We could say for all short term management, for example everything on the MCDU which is in front ... in my opinion .. it's not acceptable that this is digital [. . .] when you touch [a physical button], if you get the wrong button and you're flying at the same time, you say to yourself: 'something is not right'. We'll make the connection. "* (3).

Challenges and key concepts for embodied interaction in the future cockpit

In the following, we draw implications for design based on our analyses of transferred perception, awareness levels in control, compressed externalization in speech, disconnected and free interactions in speech and gestures, and embodiment through rhythmic temporal structures.

1. Sensory-rich interactions

The distance maintained by the pilots toward their own bodily perception, while understandable as transferred perception, raises challenges for TEI design. First, designs involving haptics may be explored with caution: pilots value enhanced perception [43], rather than enhanced reality. Pilots are suspicious towards expressive representations [29], even for abstract tasks [12,7] which advises against using physical representations of digital data [66], in line with studies that highlight the potential safety outcome of synthetic vision systems [4, 55]. Using reality-based interaction [37] would consist in applying naïve physics, which is debatable for the highly trained engineers that pilots also are. Above all, it would be probably irrelevant for the modified and abstract awareness of their body and environment. Finally, pilots are quite suspicious towards direct interaction using the body, be it only the arms [25] or the palms [23]. A pilot indeed criticized a palm-based prototype for selecting frequencies: "*How the other pilot can check if it's been done properly, under stress if he is uptight, how he's going to tense his muscles, this can cause problems."* (31). Relying on eyes-free, proprioceptive and kinesthetic control of physical shapes, as explored for instance through dynamic shape-changing interfaces [56,68], seems however a promising key concept (*I.a*, Figure 1).

2. Control, sensor-based interaction

TEI discusses control in several ways: 1) in standard models [35], the physical object is said to serve as representation and *control* for a digital one; 2) graspability is a founding theme [20]: to grasp is a physical gesture to hold an object, with a precise control thanks to the shape of fingers; 3) shared visibility and multiple access points [27,28] provide distributed control. Control is also discussed as an issue in TEI when using context-aware systems [16,63]. The background mode of control involved in such systems actually challenges the need for pilots to interact in foreground mode, especially when using instruments. As one of them said about interaction with such instruments: *"There are no involuntary actions"* (12). As a result, we explore context-aware features, such as gesture-based or gaze-based interactions, as long as they can be controlled and customized by pilots [16, 63], and provide a reasonable level of system state awareness.

3. Externalization, spatial-based design

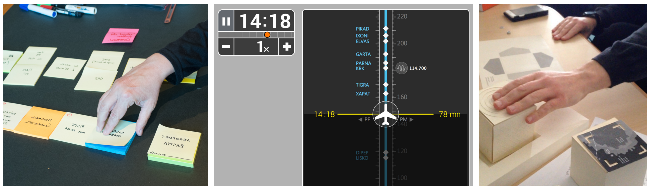

Figure 3. a) Prototyping a tangible briefing; b) a timeline; c) tangible cubes for data management and crew collaboration.

Distributed cognition in the cockpit has been studied [52], showing how pilots use paper and physical cues to support activity. A pilot who had a demonstration a tangible augmented system for ATC [31] told us how Boeing pilots sometimes use a dust-cloth as a constraint [53] to prevent them from wrongly changing the current frequency on the radio panel. We are interested in supporting distributed cognition, possibly using properties of oral communication as a major means of externalization. We indeed observed that speech is a lightweight, *compressed* and efficient way of externalizing cognitive concerns, which challenges spatial-based interaction, especially when using physical objects. During a workshop, we explored the idea of a tangible tool to run briefing (Figure 3.a), but the pilot was highly reserved towards the idea. *"In such conditions, over 4 flight legs, … well I mean, it's a bit of a marathon. It's not that you have no time, but you have to manage your effort. And you are not going to lose … you can't consider every case. For such a briefing, you just need to highlight what is important. We prefer a strategy where you say, ok, something has changed. You do a holding pattern, you take the time to do everything properly to make sure it's all as it should be."* (33). With this key concept of compressed and lightweight externalization for short-term physical tasks in mind, we explored ideas involving spatial interaction for long-term tasks. Spatialization of time has been studied through a timeline in a student project, involving two pilots in design sessions. A first pilot participated in a brainstorm to generate ideas and detailed scenarios about the features of the timeline. The second was invited for a design walkthrough of the developed prototype (Fig. 3.b), and emphasized the usefulness of these tool for collaboration, mutual awareness and sharing of the flight data. The idea of a physical cube aimed at reducing data complexity and supporting collaboration was explored with another pilot (Fig. 3.c). He confirmed their relevance as customizable tools to interact with aircraft systems for long-term strategic tasks. Relevant properties of these cubes include leveraging pilots spatial inferencing skills [33,41] while avoiding spatial cluttering.

4. Protected space of interaction

Another important property of speech is that it is "disconnected" from the system (*II.b*). This property is all the more true for gestures, which are currently an essential resource for control, monitoring and collaboration, and are not recorded at all. This refers to a potential need for a protected interaction space, where interactions could be modulated into various types, from free annotation to speech, involving tasks that already include flexibility, individual preferences and practices towards procedures, for a pilot *"has their own favorite habits."* (34). In such a protected space, levels of user control can also be flexible, letting pilots decide freely to be sensored or not [63]. Pilots mention the value of having tools separated from the aircraft systems. Speaking about the physical QRH (Quick Reference Handbook), that you can hold in your hands, a pilot valued it in case of degraded contexts, when there is no longer control available *"And in some way, it's a physical thing that is independent from the plane. Something which comes onto the screen, you may say, 'ok, it is still linked to the plane'. Here it's something serious, but it's dematerialized from the aircraft and physically I am holding it in my hands."* (35). This concept of proximal and protected interaction space, while not completely "offline" [19], seems to be the right place for tangible design.

5. Embodied temporal and rhythmic structures.

We analyzed the observed rhythms in the activity as an important embodied resource. We see in the properties of rhythmic structures a potential to help the pilots go back and forth from automatic, background or ready-at-hand interactions to present-at-hand and voluntary actions. We have started to explore how to translate these properties into our design space, using principles related to homogeneous repetitive physical structures providing a spatial equivalent of a duration. This type of structures, which are the objective of on-going work, could provide the pilots with a meaningful frame for interaction and collaboration.

CONCLUSION

In this paper, we seek to understand pilots' activity in order to inform TEI in the future cockpit. A first level of analysis is provided through key findings, based on interviews where pilots describe their activity in their own words. At a second level of analysis, we build an interpretation of elements related to perception and control using concepts drawn from the phenomenology of perception and technical actions. In particular, we suggest the idea of a distributed bodily space articulated into two separated environments and involving two levels of perception and action. Based on these key findings and interpretation, we discuss design challenges and concepts for "in-the-sky" embodied interaction. Challenges lie in the emphasis on rich sensations and representations, and in the use of physical objects to support externalization or sensors to build a connected space. Key concepts include kinesthetic control of graspable shapes, compressed externalization, customized context-aware interaction, protected interaction space and the use of rhythmic structures.

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