The 21st Century Cockpit: iPad Related Activities and the Affected Cockpit JCS

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Abstract

In aviation, pilots engage in safety critical activities in the cockpit to guarantee a safe flight. Throughout history these activities have been transformed by introducing new artifacts in the cockpit, such as rules and technology, changing thereby the way in which pilots try to achieve safe flight outcomes. The recent introduction of the iPad in the cockpit of airlines, as part of the process of developing a paperless cockpit is an example of such an artifact changing the substance of work. However, little attention has been given to the challenges the iPad introduces in piloting and in the cockpit. This thesis studied use of the iPad and the iPad as agent in the cockpit by combining an activity theoretical approach with a joint cognitive systems perspective. The iPad was found to be a rather fluid cognitive agent in the cockpit that needs to be attended to by the pilots. The iPad was found to require more attendance than expected by pilots, and to propagate wrong data into the cockpit ecology. The introduction of the iPad in the cockpit, in short, was of a transformative nature, as its introduction changed piloting and even the functioning of the whole cockpit ecology, not just for the good. The iPad, despite its being a state of the art artifact, lacks qualities that are necessary to be a team player and can best be conceptualized as a piece of unruly technology.

Table of Contents

List of Figures:

List of Tables

Foreword

In my experience, the introduction of the iPad as an innovative artifact to further cockpit operations in airlines has also been perceived as symbol of progress that is implemented as established fact, for the sake of progress. This scepticism was also found outside the cockpit. A playful though truthful critique on the iPad can be found in an advertisement from Ikea who developed a satirical advertisement promoting the 'bookbook', their paper catalogue, in iPad language. This bookbook was so innovative, its specifications were summed up: 'no cables, fully charged for life, the interface can expand in a double page, pre-installed info, no lag each page loads directly, save for later by folding over a page.'

The iPad is there, in the airliner cockpit. The question that this research aims to answer now is: How did the iPad influence flights and pilots at work?

The words of my research supervisor still echo in my ears: now just go and investigate. Back then I was at the beginning of my thesis research, but it is an instruction that will remain relevant for this implemented device and its future dealings.

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I am grateful for the opportunity to study at Lund University. This is the place to express my gratitude to colleagues, friends, relatives and my academic mentors. I extend my thanks to everyone who contributed to making intellectual endeavours possible, professors, office managers, cleaners and those who arranged the ‘fika’ (a Swedish afternoon snack).

Javier Santos and Achim Neuhaus: to study or not to study, that was my question. You helped me decide, and Javier, I tried to ensure I did not become a worse person. Ramon Cid and Miguel Palacios, you provided me with personal support and created the possibility to focus better on writing this thesis.

To my dear family, thank you for adjusting to the moments when I needed to concentrate on my studies. Fellow students, your contributions to the learning labs and our shared free time were invaluable and enjoyable. I am also very grateful to Fr. d’Agostino who passed away in 2023, his interest, priestly advice and encouragement were like that of an older brother, helping me through my studies.

Anthony Smoker, thank you for moderating the learning labs, posing crucial questions for future research and responding to e-mails so promptly. Gwendolyn Bakx, I deeply appreciate your efforts and ability in supervising the thesis writing process, creating clarity and structure in your guidance. It was a journey during which I learned so much.

Finally, in this thesis, I studied the earthly matter of work. I have been motivated by the message of Saint Josemaria, who opened up a broad panorama to so many people by teaching about the spiritual significance of work and how to elevate it to something supernatural, as part of sanctifying daily life.

1 Introduction

The cockpit is an environment in which pilots control high-risk processes to perform a successful flight. Airlines started to introduce the iPad as an instrument to perform cockpit management since 2010. Work on the iPad in the cockpit concerns both structured tasks that have clear guidelines to follow, such as aircraft performance calculations, as well as non-structured tasks, which involve the use of navigation charts or other data retrieval for which the task, its moment, or the type of data that is used, are not or less predefined. The iPad substitutes work for which paper was previously used. The iPad was part of the prelude to a broader process of digitization and developing a "paperless cockpit" in commercial aviation. Aviation authorities categorized the iPad as an EFB (electronic flight bag). Much more can be said about EFB certification categories, but that is beyond the relevance and scope of this study.

My organization introduced the iPad primarily as a weight saving measure. In my situation, two flightbags, filled up with aircraft and company related books, airport charts and maps were removed from the cockpit with the introduction of the iPad. Furthermore, the briefing package – documentation related to each specific flight – were now found in the iPad rather than printed on paper. In addition, however, the iPad introduced new dimensions of work in the cockpit. It also introduced new activities that (depending on the pilot and circumstances) can take place during flight, such as reporting and checking of detailed passenger information.

The introduction of the iPad was my company's first encounter with an EFB and the process removed almost all our paper documentation from the cockpit. As an airline pilot, I was one of those pilots that had to transition from paper to the iPad. In my company, pilots use their own iPad that they receive from the organization. Each pilot's iPad is mounted in a device in the side-window frame.

Perry and Wears (2012) showed it would be too reductionist to accept a process of digitization as 'simply substituting paper'. Something was added to achieve digitization. What was removed from the cockpit in a physical sense was mainly the use of paper briefing packages, aerodrome documentation, and aircraft and company manuals. What is added by digitization according to Rijsdijk and Hultink (2009) are attributed principles, such as autonomy, adaptability, reactivity, multifunctionality, human-like interaction to define smart products like an iPad. These attributed principles indicate that the introduction of the iPad in the cockpit did much more than remove paperwork. It also introduced a world of new relationships and new capabilities that will change a pilot's job compared to working with paper.

From a high reliability organizations (HRO) perspective, operators like pilots in a cockpit constantly construct safety through collective and individual agency (Rochlin, 1999). When new technological devices are introduced into the cockpit, like the iPad, a new agency is added to interact with, of which it can be said to take part in the joint cognitive system (Hutchins, 1995, pp. 266, 287). It is to be expected that new forms of practice may emerge from this (Dekker & Woods, 2002, p. 242) and that existing forms of practice can transform. Like I said, my organization primarily introduced the iPad as a weight saving means. The digitized flightbag that resulted though, asked for a whole other way of working, of flight management. Over time – made possible by its digitized character - more and more tasks were added also, such as the passenger administration. Knowing more about these new practices and transformations can tell us then a lot about how operators construct safety in this new situation with the iPad, and about the possible costs that come with these new practices and transformations.

1.1 Perception of iPad in Aviation

The United States Aviation authorities categorize the iPad as an EFB (Federal Aviation Administration, 2011). This category[1] was developed with regards to the ongoing transition from paper to digital sources in the aviation industry. An EFB can be understood as any electronic display system (with hard- and software) that is capable of displaying a variety of aviation data, and performing basic calculations for the purpose of supporting flight management tasks (e.g., performance data, fuel calculations, etc.). However, with the ongoing computerization developments (microchips, software and hardware), the substance of this category became rather broad, and the transformations of these devices are continuously in progress.

We can discuss the iPad as an example of a commodity that can be bought in public stores, to serve as an EFB. Conventionally, any device that was to be used for any substantial task in the cockpit, had to be specifically designed and tested. However, the iPad was readily used in the cockpit as a commercial off-the-shelf product, rather than some tool that was specifically developed as an EFB. In general, it is not unusual that positive aspects of such off-the-shelf innovative tools are used quickly in operations, while negative aspects are easily overlooked (Hollnagel & Woods, 2005, p. 2). This was also the case when the 'position of the airline industry' was presented during an EASA EFB workshop. Here, three positive aspects were attributed to EFB's, namely: an enhanced flight safety, an improved fuel efficiency and optimized flight ops processes (Sebastian & Bloemsma, 2013). Over time, an increasing number of airlines introduced the iPad as EFB. Possible downsides were not mentioned. Airline managers introduced the iPad as a meaningful tool for their airline operations. At the

[1] Fractional jet operator, Flight Options, was one of the first to outfit their entire fleet of 88 business jets with EFBs in the summer of 2000. This effectively forced the FAA to develop the FAA's Advisory Circular entitled AC 120-EFB (Fitzsimmons, 2002).

same time, documents from both regulatory authorities (EASA and FAA) [2], as well as from my own organization (an airline) [3] acknowledged, while welcoming the iPad in the operational environment, that the iPad can introduce additional workload, fixation and distraction. These aspects point out a possible undermining of primary piloting tasks. With the iPad, in other words, a source of risk is introduced, not just a helpful means.

Antonsen (2009, p. 189) once stated in the wake of the NASA Challenger disaster that members of NASA were all 'caught in a web'. He explained how the whole organization, managers and engineers, had suffered in this context, from system bias that brought forth a normalization of deviance. A culture of production and time pressure appeared to have imposed upon the NASA organization, while (structural) secrecy prevented certain parts of the composed organization to share information with other parts. About these kinds of webs, Bob Scholte points out that 'one cannot merely define men and women in terms of the webs of significance they themselves spin, since a select few do the actual spinning while the vast majority is simply caught' (1984, p. 540). Bodker (1996), in turn, proposed that artifacts could act in these webs of activities as instruments. The iPad, in this sense, could be regarded as one of 'the select few' that spin the web, and thus as a common denominator in piloting. Activity theory indeed designates artifacts such as the iPad as a mediator in (new) activities and culture (Kaptelinin & Nardi, 2009). The situation of an industry working in a certain manner (in this case, with the iPad as an EFB in the cockpit for daily use), resembles much what Antonsen pointed at.

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[2] An unofficial EASA document mentioned: 'Procedures should be designed to mitigate and/ or control additional workload created by using an EFB system' (European Union Aviation Safety Agency, 2019, p. 165). The FAA (2017, p. 11) mentions 'special attention should be paid to new or unique features affecting pilot performance' and 'EFB applications must not cause a distraction…'

[3] An organizational document on pilot operations states: 'The pilot flying may only use the EFB when workload allows. Controls shall be transferred if extensive use of the EFB is needed by the PF.' And: 'Avoid fixation on the display or distraction from primary crew duties while using the EFB.'

1.2 Perception of Mobile and Interactive Devices in Other Sectors

In a search for more knowledge on this topic, I initially compared the use of iPads in cockpits and the use of mobile phones in cars. I did this because, while countering with myself a tendency of 'distancing by differing' (Woods, 2004), I saw similarities between these two domains. Both situations involve (tacit) interactions between a user and a digital device, and both devices are located in a moving vehicle that has to be kept under control. Many countries have forbidden the manual handling of mobile phones while driving because of the inherent association with a decrease in road safety, which greatly contrasts the push to use the iPad in the cockpit. Naturalistic studies on using mobile devices while driving cars have confirmed greater crash risk, especially on visual-manual tasks, such as texting and internet usage that involve visual and cognitive demands (King et al., 2017, p. 23). Working as a pilot myself, I also experienced how these kinds of visual-manual 'tasks' on the iPad, e.g. the insertion and retrieval or modification of data, can interfere with steering the aircraft, both on the ground (taxiing) and during other flight phases. This experience, together with the studies on mobile phone use, made me doubt the legitimacy attributed to the use of the iPad in aviation.

To study such 'tasks' in the cockpit, this research has activities as subject of inquiry by using activity theory. Activity theory is used to substantiate the human-artifact model, this model juxtaposes the way in which the human uses an artifact and the way in which the use of the artifact was designed.

1.3 Activity Theory and the Wider Cockpit Ecology

Antonson (2009) pointed out that unwanted side effects in organisations often are the result of system biases and that these side effects can have effects outside the direct system.

The interferences that the iPad introduces, therefore, might transcend (as in lay beyond) the cockpit environment.

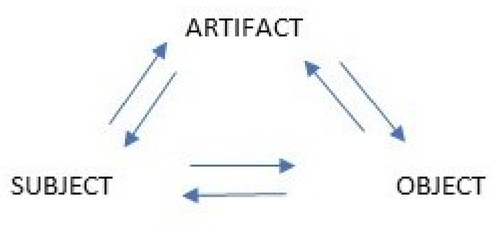
Studied was therefore, how the iPad influences piloting and the consequences of that in the wider system, the cockpit ecology. Activity theory served as a framework, a lens, to study how the iPad relates to the work system. From this perspective, I studied how the digitized aspects of the iPad interact with the other coordinative tasks of cockpit crewmembers during flight, how the iPad may influence flights, and how all these interactions with the iPad over time may ‘cascade’ even, into unwanted consequences such as an aircraft unintendedly deviating from the intended trajectory.

Activity theory is specifically concerned with understanding actual work, i.e., with what happens in practice. Activity theory studies how individuals relate to artifacts that act as mediator to certain practice (e.g. the iPad). As the name depicts, it takes activities central, in this case the flight management tasks in the cockpit. It investigates how work and the cognitive aspects of it are distributed over the different agents (men and artifacts) in the system. In my research, the artifact (iPad) has been considered as having a mediating role to arrive at a chosen object. Because of all this, activity theory was regarded a good framework for studying how work and activities in the cockpit (as well as the cockpit ecology as a whole) have actually been transformed by the iPad.

A most basic representation of how individuals and artifacts relate to each other in a work system, according to activity theory, is that activities in the system are mediated by purposeful interactions between subject (e.g. human) and object as is shown in Figure 1 (Kaptelinin & Nardi, 2009, p. 42). These interactions on their turn, produce outcomes.

Figure 1

A basic visualization of activity theory



The scope of this research extends its analysis to the level of the cockpit ecology because the effects that the iPad introduced are not confined to the pilot interacting with the artifact. The research therefore includes Woods's and Hollnagel's (2005, p. 19) notion of joint cognitive systems (JCS). The domain of JCS, according to Woods and Hollnagel, focuses on the cognitive performance of whole systems (including both social and technical agents that both hold some form of cognition). JCS, in other words, provides a way to join the collection of human(s) and machine(s) into one system, and describe how they function together in a particular environment. The notion of JCS is, in this research, thus used to relate the 'pilot and iPad' to the wider cockpit ecology.

1.4 Research Questions

The aforementioned, namely:

1) the widespread use and social acceptance with airliners, regulators and others of the iPad in cockpit duties without, so it seems, any reservation and

2) the literature that suggests the introduction of the iPad is more than substitution of paper alone, and can be a source of distraction that can affect other primary flight duties

provides reason to perform an explorative study on the relationships and interactions that this iPad has introduced in the airliner pilot's jobs, on how it interacts with other tasks and may 'cascade', possibly, into unwanted consequences on a macro-level, with which I refer in this research to the performance of an aircraft in relationship to its environment.

My main research question is:

- In what ways do iPad related activities with its inherent digitized aspects interact with other coordinative tasks of cockpit crewmembers during flight, and how does it influence flights?

The activity theoretical approach in my research guides me to focus on activities that are formed by the relationship between a subject and an object through an artifact. With that in mind I developed the following sub-questions to answer the main question:

- What did flight operational activities related to the iPad look like before the iPad introduction?
- What activities does the iPad introduce and mediate in flight operations?
- How do cockpit crewmembers and the iPad interact?
- What are the pros and cons of the current situation for cockpit crewmembers, and for flights in general?

First, however, I studied the literature on this topic, using thereby the following theoretical question:

- Where new technology is introduced, can activity theory serve as a tool to scrutinize how work changes in a joint cognitive system and relate these changes to the introduction of the artifact?

2 Useful Literature

The iPad participates in the cockpit ecology and together these can be seen as a joint cognitive system, as human and technological cognitive functions that collaboratively form the work system. The iPad in this system is subjected to the cognition and intention of pilots during flight operations, while the pilots vice versa are subjected to the iPad's 'intentions' and 'cognition'. The theoretical foundation of my research, in other words, relies on cognitive concepts. Rasmussen (1997, p. 209), when discussing risk management in a dynamic society, labelled the focus on cognitive aspects (e.g. by description of behaviour and by understanding behaviour shaping features and criteria) as especially 'promising' with regards to the study of failure in socio-technical systems.

In line with Rasmussen's insights, previous ethnographic studies have been performed on air traffic control and hospital work domains on the introduction of digital tools which substituted a paper tool (Huber et al., 2020; MacKay, 1999; Perry & Wears, 2012). These studies give an idea on what studies in my research domain could look like, for example by pointing out ad hoc adaptations by workers, new bottlenecks, ways in which work was coordinated and cognitive efforts placed or used by workers. In this research I aimed to study these cognitive aspects in the interaction between pilots and iPad in the cockpit ecology through activity theory.

In the introduction, I laid down that activity theory is specifically concerned with what happens in actual practice, i.e., with the work-archetype called work-as-done. In this section, I will therefore first discuss the conceptual difference between work-as-imagined and work-as-done. In this actual practice, the iPad and pilot working together have to be conceived as an open-ended system 'whose local behaviour is undetermined by any overall rationality' (Wynne, 1988, p. 147). This means that work that is prescribed from an overall rationality that does not include this open-endedness, is incomplete and imaginary at best. Practical work, in the end, can only be described by understanding local actual behaviour. In this way, I attempt to apply activity theory (through the application of the Human-Artifact model) to scrutinize the activities in which the iPad is involved. In this chapter I discuss both the human-artifact model and activity theory. Joint cognitive systems will also be elaborated upon, after which I will move on to how these theories were integrated and conceptually overlap each other to a certain extent.

2.1 Work as Prescribed and Work as Done

To perform activity theory, a valid description of activities is necessary. There is a difference between accounting for activities by referring to formal sources and accounting for activities by looking at real practice. In recent safety science, different archetypes of work have been developed (Shorrock, 2016). The primary four are work-as-disclosed, work-as-imagined, work-as-done and work-as-prescribed. Because activity theory studies activities in real practice, this research, focuses on work as prescribed and work as done.

Work-as-prescribed is the concept of work that regards work in terms of rules and procedures. It is a formal description of work, and there is often a limited variety of this type of work. According to Shorrock (2016) it is ‘unique among the four key varieties in that it is assumed to be the safe and the right way to work. As such, it is … to control and standardise work-as-done.’

Work-as-done (Hollnagel, 2014) is a concept of work that regards work as it is occurring in the naturalistic setting. This concept engages into actual activity, - in what people do, their actual problems and work practices.

The conceptual difference between work-as-prescribed, and work-as-done can point out a gap between the way work is formally specified and the way in which work is performed (Hollnagel, 2014). Awareness of this gap should be of concern for any organization putting forth work-as-prescribed, because knowledge of the gap helps to understand the operational challenges so that it can improve operational performance and thereby the wellbeing of the actors therein. Work-as-prescribed is thus studied so as to get a better comprehension of work-as-done.

Getting an idea of work-as-prescribed is easy. One only needs to find the formal documents, and to combine these for a description of the work. Getting an idea of work-as-done is more difficult. This requires an understanding of actual and distributed work, how this is done and distributed by actual workers with actual experiences and interpretations, in actual and often complex situations.

In this study, work at the sharp end is studied besides work-as-prescribed. Work at the sharp end resembles much features of work-as-done as the sharp end of an organization refers to that end of the organization where the actual hands-on work takes place. At the sharp end, usually multiple tasks are performed, in dynamic environments, in which work is an ongoing adapted activity. This entails that the sharp end makes performance adjustments during everyday settings to let work go right. Cockpit crewmembers are in this case a main resource for finding a better understanding of the distributed cognitive system that these pilots work in.

2.2 Activity Theory

With the introduction of new technologies, a world of ‘prospective configurations’ is introduced, ways in which engineers intend the technology to be operated. These configurations, however, remain fictive until they are ‘filled in by agency’ (Rip, 2009), in actual practice in certain ways. To understand actual and distributed cognitive work in collaboration with the iPad therefore, the iPad being the mediating artifact in this case, one must determine how agents (iPad and pilots) deal with these configurations (as in adapt to them) and how they are filled in. For that purpose, activity theory is applied in this research.

'Activity theory is based on the idea of the dialectical process of man and artifacts shaping and being shaped by' the environment (Nathanael et al., 2002). Activity theory keeps the goals and motives of all the agents, both human and artifactual, in the system in mind when studying how activities are introduced and develop between subject and object, and how artifacts mediate therein. It is from these dependencies, between man, artifact and environment, that differences between work-as-done and work-as-prescribed emerge. Activity theory in this way, will help analyse the inner structure of activities and work as a 'heuristic device' (Vaughan, 2016, p. 457), with which I mean that activity theory directs the selection and collection of data by focusing on 'activities' as substance of work. It helps me interpret what activities take place and how they unfold during work.

Activity theory is found to be helpful since it designates artifacts as (possible) mediators of activity and culture (Kaptelinin & Nardi, 2009). By analogy, Bodker (1996) described artifacts as instruments of a web of activities. With this she means that artifacts can be used in many ways, but that the use is shaped in a "web" that belongs to a certain community of practice, such as software developers who update an iPad aviation apps, or pilots who use the iPad during flight.

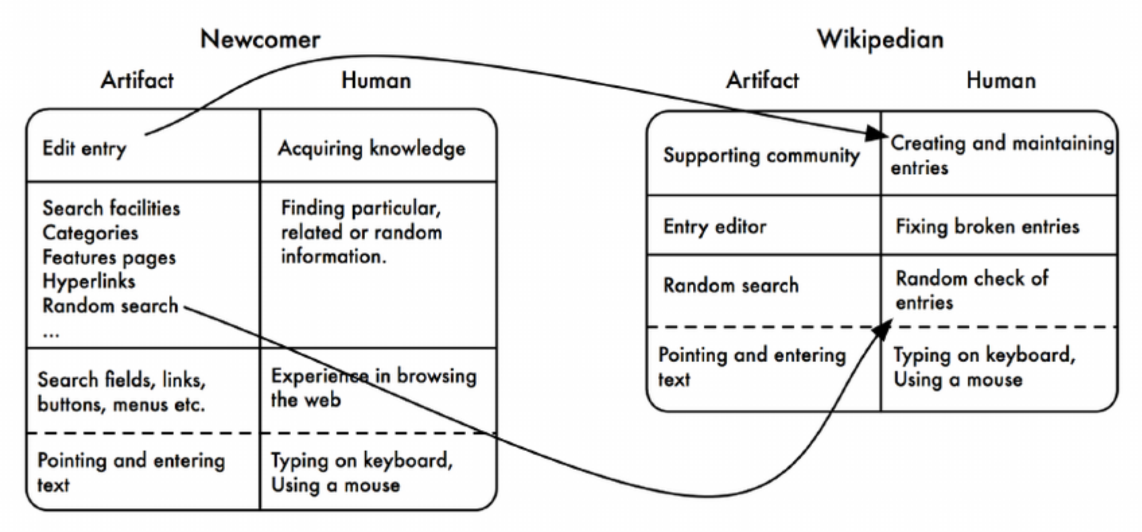
In the dialectical process between man and mediating artifact an activity may encounter difficulty in being realised. Winograd and Flores (1986, pp. 77–78), who drew on ideas developed from phenomenology, mentioned that *breakdowns* in functioning could reveal to us "the nature of our practices and equipment", and thereby the nature and working of the mediating artifact. The activity theoretical approach allows me to understand not just the intended uses of the iPad, but also how it is integrated into pilots' work, revealing the practical realities and adjustments made in response to the artifact.

2.3 Human-Artifact Model

Bødker and Klokmose (2011) developed the human-artifact model (see Figure 2) to substantiate activity theory with a helpful tool. The model has originally been developed to study human-computer interaction (HCI). It provides a structure to systematically arrive to an understanding of artifacts in relationship to their users (Bødker & Klokmose, 2013, p. 4), as well as to the structure of the activity itself. It does this by mapping out distributed cognition in the system.

Figure 2

Example of the human-artifact model filled out for two types of Wikipedia users



Note. *From Bødker and Klokmose, 2011*

What makes this model particularly compatible for my research is that it distinguishes itself from classical HCI by paying attention, in its attempts to map out distributed cognition, to the actual use and complexity of multiuser activity by addressing in particular the artifact as mediator of human activity (Bødker and Klokmose, 2011, p. 319), rather than simply focusing on tasks (Wilson & Sharples, 2015, p. 391). The model juxtaposes the envisioned artifact – its ideal use – as well as the user's use. As such, it can help pointing out gaps between design (artifact column), that was previously discussed as work-as-prescribed, versus use by the human (human column), which was previously discussed as work-as-done.

The human-artifact model provides three levels of human orientation, to analyse in this way both envisioned and actual activities (see Table 1): the activity level, which is connected to the longer term motive, i.e. going from A to B as quick as possible (by flying); the action level, the level at which is aimed for certain results in order to achieve a certain activity, i.e. maintaining an altitude with a certain speed; the operation level, consisting of operational sequences to attain a particular action, i.e. reducing or increasing engine thrust or pulling and pushing the steering column to maintain speed and altitude.[4] The model prescribes to perform an analysis for these three levels, on how the interaction between men and artifacts can be abstracted and structured by asking for every activity: how(?), what(?) and why(?) (see Table 1).

The why question analyses activity by motivation, by why a certain activity is undertaken. The answer to why a pilot uses an airport diagram, for example, can be to navigate the airport. The answer to why the iPad can show an airport diagram could be to present a clear layout of the airport. The answer to these why questions give activities and the underlying action meaning. The what question is goal oriented and focuses on the supposed result of an action that is ordered towards realizing a certain activity.

The operational sequences (operations) can be abstracted by asking ‘how’ the actions within an activity are performed in concrete terms. This how-level is divided in learned handling on the one hand, which focusses on learned assumptions and routines in handling, and adaptative handling on the other hand, which focusses on real-time adaptations to the

[4] An activity consists of actions, but similar actions can occur in different activities. The operational sequences depend on the context. Stable air, for instance, is a condition in which little operational sequences are needed, while gusty conditions require coordinated manipulations of engine thrust and steering column. It could even require the use of the speedbrakes, to prevent an overspeed.

physical conditions. A pilot might, for example, have learned to move from one chart to the next by swiping the iPad screen with four fingers. If after an update this function no longer works, the agent needs to adapt and develop a new sequence until this new sequence has been internalized again, and has become learned handling. The human artifact model makes it possible, in this way, to study the manner in which activities can hold both regularities (e.g. learned handling) and irregularities (e.g. adaptation to unforeseen iPad behaviour) (Hollnagel & Woods, 2005, p. 59). It thus helps to study, in this research, how the interactions between iPad and pilot, the collaborative 'iPad+pilot' system, can propagate in activities to control the aircraft's path on the ground and during flight.

Table 1

Human-Artifact model, augmented with the analytical key questions and hierarchical structure of levels of activity in the fourth column

Analytical Key questions	Artifact (iPad)	Human (pilot)	Levels for activity
Why? ↓ ↑	Motivational aspects	Motivated orientation	Activity Longer term motive ↓ ↑
What? ↓ ↑	Instrumental aspects	Goal orientation	Action Aiming for specific results ↓ ↑
How?	Operational aspects: 1 handling aspects 2 adaptive aspects	Operational orientation: 1 learned handling 2 adaptation	Operation sequences of action (condition)

Note. Taken and modified from Bødker and Klokmose, 2011

2.4 On (shifting) the Unit of Analysis – Joint Cognitive Systems Team Player Concepts

A unit of analysis must be chosen in any research, to distinguish the unit that is to be studied from context. This is necessary to attribute qualitative and interpretive judgements about the relationship between unit and context and afterwards, to make a sound analysis of data. This is one of the reasons why the field of JCS is included in this study, to help define the unit of analysis that is to be studied by activity analysis.

The theory of joint cognitive systems gives an account of work in everyday socio-technical settings. It proposes to analyse users and artifacts in a holistic manner through a functional category called co-agency (Hollnagel & Woods, 2005, p. 19). Joint agency is a central aspect that usually refers to 'what these joint agents, compiling a system, do'. Such a holistic approach would cover a system from micro- to macro-level. Vaughan's work with NASA supports to shift in the unit of analysis in research. She explains how shifting a unit of analysis (e.g. between micro- and macro-level analysis) can help better explore relationships between the environment, the organization, and individual behaviour (Vaughan, 2016, p. 457).

Co-agency focusses on the harmonization of functions jointly performed by both 'humans and artifacts' in micro to macro cognitive structures in order to perform certain tasks, (parts) of tasks and cognitive functions are thereto distributed over human and artifactual agents in these kinds of systems. This fits activity theory. This cognitive structure with these cognitive functions should thus be studied as a whole, as separating these would be reductionist. The compiled system (JCS) in this research thus encompasses the pilot and the iPad in its wider cockpit ecology.

The literature of JCS facilitates, furthermore, a number of concepts that can help in discussing the activities and goals in systems in a meaningful way. It allows to evaluate the quality of an interactive system (Woods & Hollnagel, 2006), which is applicable to my research. The interactive system here comprises a condition in which pilots, the iPad and the cockpit ecology perform the flight management together. They have to work as 'team players'. Klein et al. (2005) developed concepts that point out requirements for cognitive agents, men and artifacts in the system, to act as effective team players that engage in Joint Activity. 'Common ground' is one of these requirements and refers to pertinent knowledge, beliefs and assumptions that are shared among the involved agents (Klein et al., 2005). According to Klein et al. common ground is 'perhaps the most important basis for interpredictability', which is the second requirement for Joint Activity. Interpredictability supports the interdependent actions between team players. For example, for a pilot knowing that the autopilot maintains a stable flight path, that it creates predictability, allows the pilot to perform actions on the iPad and prepare information for future flight phases. The third requirement for Joint Activity is directability, since conditions can change and the agent must be able to modify actions of another partner. For example, an aircraft might be heading towards a dangerous cloud that is not visible for the eye, as the flight occurs at night. The weather radar makes this cloud visible on the screen, that information would direct the pilot to modify the aircrafts trajectory. Common ground, interpredictability and directability are key concepts for managing and keeping control in dynamic work situations, and thereby keeping the work system viable.

For this research, two different hierarchical levels of the JCS were chosen. Focus of the research is first on 'pilot+iPad' (micro). Thereafter, a more integrated and holistic level of analysis has been taken, by studying, inspired by the JCS perspective, the 'iPad+pilot[5]' + 'cockpit (ecology[6])' in an attempt to raise the understanding of the larger system considered in

[5] Pilot includes co-pilots and captains.
[6] E.g. the other pilot, flight instruments, windows, and the flightphase related duties or tasks.

this study. This level has been regarded the meso-level in this study. This means I have not studied actors outside the cockpit JCS, in other parts of the organization for instance. My research did, however, implicitly include how some of the technical experts in the cockpit ecology may be influenced by these actors[7].

Addressing both the (meso level) cockpit ecology and the (micro level) iPad in one research, shifting thereby the unit of analysis and the relationships between them, was not foreseen by Bødker and Klokmose (2011). That is why I combined activity theory and JCS into one framework, so as to be able to discuss how joint activities take place and influence both levels of the systems. To address this, it was necessary to shift between these units of analysis.

Figure 3 contains a JCS framework of Hollnagel and Woods, in which they lay out the goals-means decomposition for more than one hierarchical system level. 'What constitutes a means at one level becomes a goal', in this framework, 'at the next level down' (2005, p.32). This closely resembles the analytic structure of activity theory (why, what, how). Table 1 and Figure 3 have therefore been combined into a micro-meso-level decomposition (Figure 4) that I developed for the two JCS levels that I considered in this study. With this framework, I managed to keep in mind the 'goals-means decomposition' throughout the discussion, regardless of the unit of analysis that was discussed.

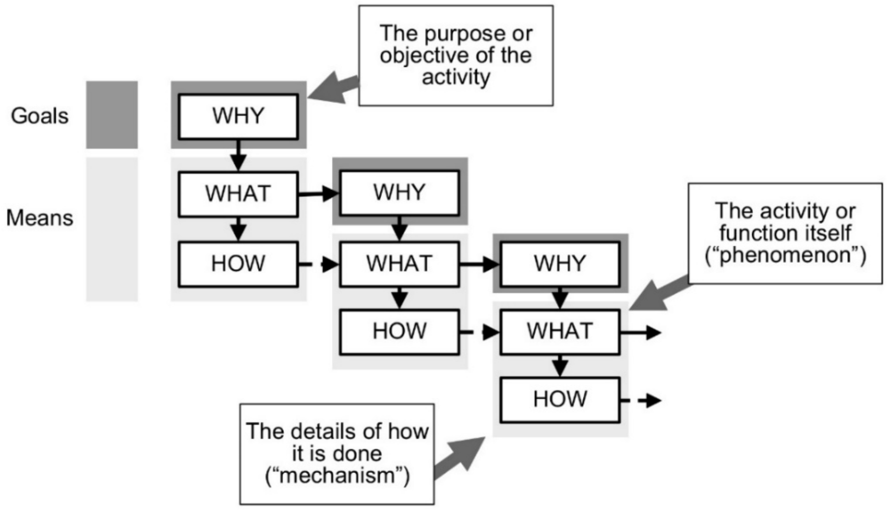
Descriptions of the 'pilot+iPad' activities have been processed during the research in the double column in Figure 4 on the right, under microlevel. The 'umbrella activity' found in the 'pilot+cockpit ecology', is processed in the left double column, under meso-level. In this way, the (different) activity analyses for the activities at the different levels have been made visible. Each activity has its own object (motivation) that brings with it (possible) tensions

[7] E.g. programmers and app developers, authors of manuals, etc.

and requirements. Some of them take place at the same time. The question was how all these activities 'align' with each other, since these all are supposed to participate in a joint activity. Figure 4 provides a basis for the formulation of an answer on this.

Figure 3

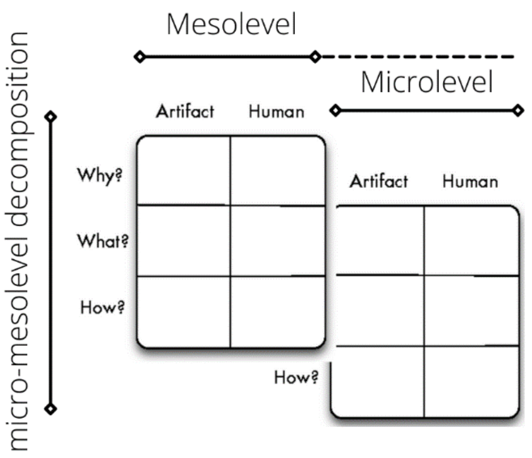
Goals-means decomposition



Note. From Hollnagel & Woods (2005, p. 132)

Figure 4

The micro-meso-level decomposition, inspired by combining the goals-means decomposition and the human-artifact model



2.5 Summary: how Activity Theory, the Human-Artifact Model, and JCS are Combined in this Research

Activity theory is a suitable framework for this research as it focusses on activities in which human actions are mediated by technical artifacts. Central in this theory is its description of the dialectical process of man and its artifacts shaping and being shaped by the environment (Nathanael et al., 2002), and by each other. Activity theory is concerned about actual activities, which is why this research explicitly distinguishes work-as-prescribed from work-as-done. Especially breakdowns in these actual activities, when work is interrupted by something, or when our attention is removed from the real object (Bodker, 1996, p. 149,150), are seen as important sources revealing to us the nature of our practices and our mediating equipment. The human-artifact model, combined with JCS, has been used to map out these aspects over the respective hierarchical system levels. The human-artifact model zooms in on two aspects which could get lost in the research. First, it focuses specifically on the difference between what an artifact and its role in the wider system was designed for (work-as-prescribed) and how the operator actually uses it (work-as-done). The human-artifact model thereby points out gaps between system design and actual operation that can bring about tensions in an activity. Because the revised model includes both the micro and the meso level, it provides a reference for discussing the influence that these tensions in the actual practice can have on flights. It focuses on activities, and on the tensions in the relationships that produce these activities. How these develop between the subject and mediating artifact are important because both the tensions and the objects that come about at the level of 'pilot+iPad' can intervene with other work activities, in which case it propagates new tensions to another level in the system.

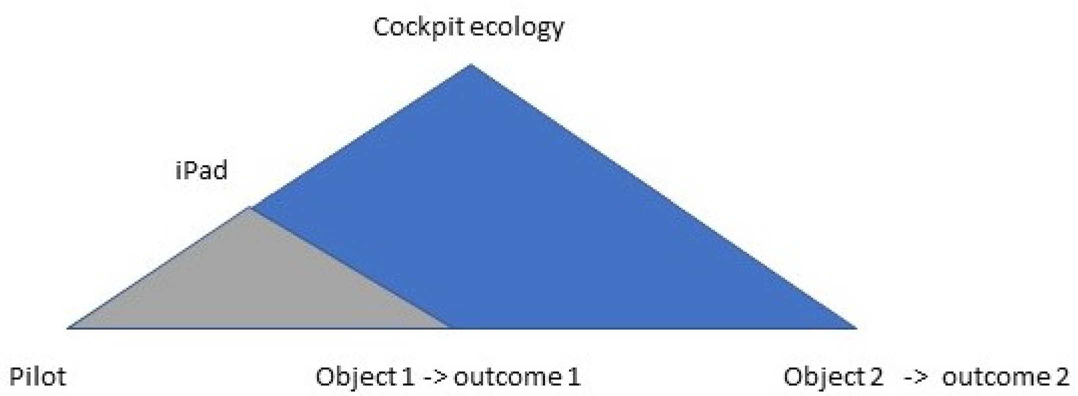
What JCS adds to this is that it introduces a more integrated view by using the concept of co-agency, e.g. joint agency (Hollnagel & Woods, 2005, p. 19). With conventional HCI, humans are physically separate from machines, in a socio-technical system such as the 'iPad + pilot' system however, they are not functionally separated at all, hence why the concept of co-agency has been used here.

JCS also puts emphasis on socio-technical context, and allows drawing a wider boundary than activity theory to define the system of interest (Woods & Hollnagel, 2006, p. 144). This, in turn, allows this research to say something on the effects that activities can have on that wider system such as the performance of flights.

Figure 5 shows the studied cockpit JCS. The pilot and the iPad participate in a larger joint cognitive system with larger purposeful activities. The system as a whole, is called the cockpit ecology. The subject is a pilot who, together with artifacts in the cockpit JCS and the iPad at the micro-level, intentionally engages into activities and manages the objects (goals) of the (mediated) activities. What happens at the cockpit ecological level influences the activities at the micro level and vice versa.

Figure 5

Activity triangle of the cockpit JCS under scrutiny, in which the pilot is responsible for using the iPad that is surrounded by the cockpit ecology, during flight operations in the cockpit, by managing objects to achieve desired outcomes.



3 Methods, Research Design

This chapter presents the research design and details on the data sources that were used. It also presents more details on how the analysis was performed, which steps were followed. At the end of this chapter, I reflect first on the rigour of my choices, and then on some ethical aspects of the research. Some notes on rigour have been included also in the paragraph on the interviews.

3.1 Research Design

No previous research was found that focused on activities introduced by the iPad in the cockpit and the way it affects other coordination tasks. Neither has the human-artifact model to my knowledge been used in combination with JCS in previous studies. Moreover, the transformative aspects of iPads continuously influence the way work is done. Work, in short, constantly transforms along with changes (updates) in the iPad, which is ongoing. For these reasons an explorative research strategy was chosen. This research means to create an in-depth understanding on the activities that emerge in the cockpit after the introduction and subsequent use of the iPad, as well as of the coordinative challenges during flights for the cockpit crew that result from this introduction.

The research methodology used in this study enabled the development of meaningful descriptions and an understanding of activities that take place inside the cockpit, and how these affect the cockpit ecology. Because of this, I used a qualitative research setup that was ethnographically inspired by relying on activity theory (combined with JCS) as theoretical tool to study practice (Bertelsen & Bodker, 2003, p. 323).

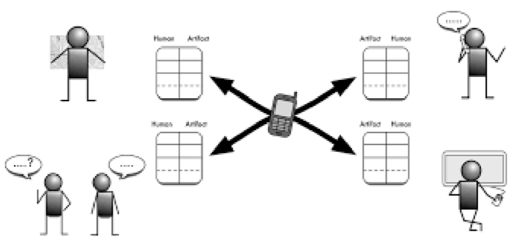
What ‘iPads and pilots do’ in this study has been referred to as work-as-done. Studying work-as-done is a difficult and lengthy process. Common restraints in time and resources for a master’s thesis made a full ethnographic study impossible. However, as a researcher I tried to stick to the ethnographic principles as much as possible. I submerged in the community of interest, which in my case is my usual work environment. For objectivity reasons I developed a systematic and standardized research setup to study the ways in which my colleagues were affected by and dealt with the introduction of the iPad. The information came from a relatively small number of informants. This is not a problem, however, because the goal was to provide a rich understanding on the insertion of the iPad in the cockpit ecology rather than to generalize or report statistically on those coordinative activities.

Studied during this research was the iPad use during short haul commercial flights by pilots in my European based organization. I chose to arrive at the knowledge that I looked for by using a combination of activity theory (more specifically Bodker’s human-artifact model) and JCS. This is because this combination of methods allowed me to study and interpret the mediating role of the iPad in its socio-technical environment, the cockpit ecology, where the pilots and the iPad work together (in co-agency) to perform the flight management activities. Cognitive task analysis would focus too much on the cognitive aspects in work (Stanton et al., 2017, p. 338), on what the flight crew know and which strategies they develop. A focus on activities in context, both of the flight crew and of the artifact to be studied, using a levelled approach, rather allowed a useful study of tensions and breakdowns in the cockpit ecology, not just regarding cognitive aspects, but of all actors together in the cockpit ecology, at all system levels. Studying the distributed system in this way, I believe, gave me the capacity to meaningfully study and convey agency in the actual and complex setting of the cockpit JCS.

In this study, I used the human-artifact model, which is based on activity theory. This model provides a framework that helps to systematically arrive at an understanding of artifacts in relation to their users (Bødker & Klokmose, 2013, p. 4). It also models the structure of the activity itself. It attempts to map out distributed cognition in the system. Bodker and Klokmose (2011, p. 342, 366) (2012, p. 6) proposed to use 'a current activity' or scenario to fill in the human artifact model from both the perspective of design and use. To study relevant activities, I made sure that the scenarios and activities were informed by pilot experiences with the iPad in the cockpit JCS. To do that, I drew inspiration from Nemeth et al. (2011, p. 197), who studied the mediating role of artifacts through an artifact analysis. Since artifacts have been developed to manage and maintain meaningful activities, understanding their use through my artifact analysis develops an understanding of what happens and matters in a work environment. Here, Nemeth et al. (2011) (see Figure 6) gained knowledge about the nature of both the artifacts and the intentions that the artifact represents by placing the artifact central in their study. In a different study, Nemeth et. al. (2004a), studied artifacts and their users by looking at activities with the artifact during work and how the artifacts are used to manage these activities (see Figure 7). This is what I have done during the activity analysis in this research.

Figure 6

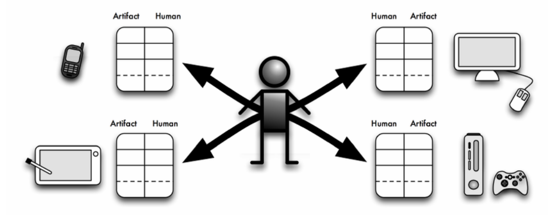
Activities perceived from artifact



Note: From Bødker and Klokmose, 2011

Figure 7

Activities perceived from person



For this analysis I looked for tensions, e.g. in the form of breakdowns, by keeping in mind the general criterium used by Bodker (2011) who looked for: interrupted moments of our habitual, standard, comfortable 'being-in-the-world' (Winograd & Flores, 1986, pp. 77–78).

This research is based on a solid theoretical basis, the research methodology started with a sensitizing phase and the development of a good understanding of the artifact. Only then, I continued by inviting the informants to speak about their activities and experiences. It also employed methods to complement each other, weaknesses of one were offset by the strengths of the other, e.g. observations could capture what was left out in speech (due to experience).

3.2 Sensitizing Phase

Due to the iterative character of the research methodology, the research contained two sensitizing phases. During the first one at the very start of the research I read ca. 560 ASRS to inform myself about possible problematic iPad activities. These were used, among other things (i.e. triangulation, contribute to transferability), to generate the activity cards and learn if certain flight phases could be identified as (typically) critical. The second sensitizing phase took place during the artifact analysis, which included one artifact interview, and continued through the rest of the activity analysis following the artifact analysis. In this phase, I revisited documents about the cockpit ecology during certain flight phases to enrich the discussions and observations during the main interviews (Appendix H).

3.3 Data Sources

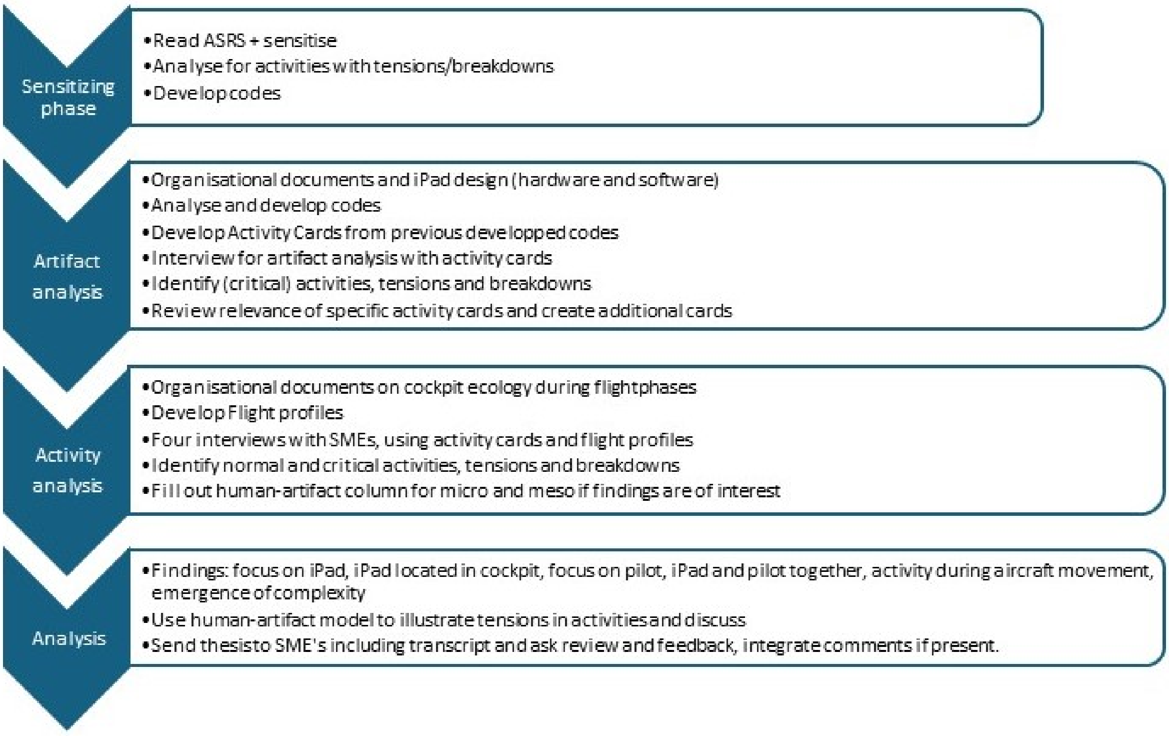
In line with the ethnographic nature of the research, data came from different sources, i.e., air safety reports, an artifact analysis, organizational documents, and interviews with informants. During the interviews, actual observations of pilots working the iPad were performed as guided by the activity cards and flight phase charts. An overview of the research design is given in Figure 8 and is further explained in this chapter.

The safety reports were primarily used (during the first sensitizing phase) to gain some idea about what issues are generally reported when working with the iPad. The organizational documents were used to build a factual formal picture of how work with the iPad in the cockpit has been described. This was useful to understand to what extent work deviates from what is prescribed (and vice-versa). The interviews were used to find out what subject matter experts (SMEs), pilots in this case, report on their actual work with the iPad, on how they interpret artifact behaviour and engage in (iPad related) activities in the context of performing flights, but also about tensions that follow from the introduction of the iPad in their work. The observations of the pilots working the iPad were used to gain a more naturalistic view of how they would work the iPad in the cockpit. Visual aids were used during the interviews to present (critical) flight phases and (critical) activities to the informants with the purpose of activating the SMEs descriptions of how they actually perform their work.

All collected data was used and triangulated throughout the research, so as to come to a most comprehensive view of what actual work with the iPad looks like. The visual aids and the observations were explicitly used to filter out rationalizations during the interviews, and to develop a richer insight in work-as-done. I do have to acknowledge however, that the observations and communications between the interviewee and me occurred in a static environment, without real time pressure, which could influence actual behaviour. In the paragraphs below I will provide more information about these data sources and address their strengths and weaknesses.

Figure 8

Design of research



3.3.1 Air Safety Reports

A search on the NASA and FAA air safety reporting system (ASRS) database produced approximately 500 reports. The reports came from the database categories: 'Air Carriers', 'Commercial Operators', 'Passenger' and 'Cargo' flights and all contained the word 'iPad'. The search term 'iPad' in my organization's database produced 60 air safety reports (ASRs). From these reports, 164 respectively 54, making a total of 219 reports related the iPad to some occurrence. Access to the European central repository (database) was not available due to legislation[8]. The available reports were scanned in an effort to sensitize myself as a researcher to the knowledge and experience produced by operators and their worries concerning the iPad. These reports help later on in the research, such as during the interviews, to identify issues with the iPad in relation to the cockpit ecology.

3.3.2 Artifact Analysis as Data Source

After having familiarized myself with possible issues in working with an iPad in the cockpit through reading the ASRs, I performed an artifact analysis on the iPad and its surrounding cockpit eco system as the first step of the activity analysis conform the human-artifact model. According to Nemeth et al. (2011, p. 197), artifact analyses can be used to gain knowledge about:

- The nature by design (the formal nature) and the informal nature of the artifact (in this case the iPad situated in the cockpit JCS), i.e., the *what* and *how* levels in the artifact column of the human-artifact analysis during work-as-done.
- The intentions the artifact represents in the activity studied (in this case flight operations), i.e., the *why* level in the artifact column (C. P. Nemeth et al., 2004).

The artifact analysis that I performed focused on what the iPad does in the cockpit JCS, and the activities it introduces. This step was implemented to approach the object of analysis, i.e. the cockpit ecology including the iPad as was illustrated in Figure 6. This artifact analysis mitigated the risk that during the interviews with the subject matter experts work would be discussed in oversimplified ways, and that details would be missed out. Overlooking the messy or complex reality would result in oversimplified conclusions.

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[8] Regulation (EU) No 376/2014 of the European Parliament (article 33)

For the artifact analysis I performed one interview with two informants. I also studied documents as well as the iPad hard- and software hands-on to learn more about the actual iPad use. The interview, the documents and the hands-on experience especially, allowed me to understand the design for activities through the iPad itself. This provided me with a conceptual picture about the nature of, and intentions represented[9] by the iPad, as well as on how formal guidelines regarding the use of the iPad work out in practice on the iPad itself. This knowledge about iPad design, iPad content and formal instructions and guidelines add to the knowledge on where the assumptions of the creators of the iPad may conflict with the those of creators of 'flight operations with the iPad'.

Based on the artifact analysis I developed the activity cards that I used during the main interviews.

3.3.3 Documents

To discuss activities taking place in a JCS, it is helpful to acquire knowledge about how the JCS is defined at a functional level, as well as information about the context in which the functions are exercised (in this case the cockpit JCS). This provides knowledge on the ways in which work is constrained. Documents were used as a starting point for this, which was supplemented later in the research with data from the interviews.

To find out the formal organizational position (or work-as-prescribed) on the iPad related activities in the cockpit JCS, I analysed company documents. Company documents contain declarative knowledge about what work and the context in which it occurs looks like, as well as procedural knowledge (how to do things) in a work context. As a consequence, company documents often 'assert consensus through [some] matter-of fact tone' (Vaughan,

[9] These representations can come from organizational actors lying outside the meso-level, e.g. iPad designers, managers, mobile data providers, and programmers.

2016, p. 248). This formal tone articulates the formal (and public) mode of an organization (Coghlan & Brannick, 2005, p. 61), previously discussed as work-as-prescribed.

What follows is that work-as-prescribed is often affirmed and taken for granted as the one correct description of work by both creators and others while work in practice never actually fully proceeds as prescribed, if only because formal guidelines by nature always underspecify actual work. A fundamental weakness in documents, for instance, is their lacking capacity to refer to the internal relationships and interdependencies in the system they are part of, that are often not that obvious (Billings, 1996). Organizations, in fact, usually comprise of not just a formal mode, which the documents often present, but also of an informal mode. Experts, for instance, 'possess knowledge and reasoning strategies that are not captured in existing procedures or documents' (Hoffman & Lintern, 2006, p. 215), and speak of their work often in terms that could be referred to as work-as-done.

The benefits that come from using documents for this research, is that discussing work-as-done in reference to work-as-prescribed provides more knowledge and foremost a better understanding on the gaps between both. The documents also helped identify the so called critical flightphases[10] that are associated with high workload and thereby indicate where these documents lack in their capacity to refer to internal relationships. Nevertheless, all flight phases were processed into the visual aids that were used during the interviews (flight profiles).

[10] The critical flightphases (including explanations) are: pushback (pushing the aircraft away from the terminal), taxi out (driving to the departure runway), line up (entering the departure runway), take-off run and take-off segments 1 and 2 (increasing speed to fly and initial climb out), flight below 10.000 feet, final approach (a phase that starts approximately 4 minutes before landing), missed approach (cancelling the attempt to land by flying up again), landing, roll out (deceleration on the runway to vacate onto a taxiway), taxi in (driving to the parking position), park. High workload phases are defined from off-blocks until 10,000 ft above the departure aerodrome and from 10,000 ft above terrain or landing altitude (whichever is higher) until on-blocks.

For this research I consulted the following flight documents from my organization about the prescribed use of the iPad during flight, as well as other prescribed requirements, activities and tasks in the cockpit (ecology) during specific flightphases.

- Basic operating manual
- Reference Guide (containing elaborative information)
- Airplane operations manual (AOM) part 1
- Standard operating procedures manual (AOM) part 4
- Performance application in the iPad
- Navigation and document application in the iPad

3.3.4 Main Interviews

Through the main interviews, part of the activity analysis and following the artifact interview, I aimed to elicit knowledge that would provide a comprehensive view on how the pilots in my organization natively work with their iPads in the cockpit during their flight. This I needed to perform the activity analysis. During the interviews, I used the flight profiles and activity cards that resulted from the artifact analysis.

Gaining knowledge on actual work from verbal accounts has limits. Bainbridge (1979), for instance, pointed out the following possible distortions in verbal accounts:

- Rationalizing and theorizing what happened.
- The unconscious knowledge cannot be verbalized.
- Conscious knowledge is not always verbal, e.g. skills with complex co-ordination.
- Language is limited, consequently knowledge is limited by what can be communicated.

Besides these inherent limitations, interviews also have a particular strength of which I made use. According to Bainbridge (1979, p. 434), for instance, verbal reports on work activities are useful specifically for getting information on a full range of behaviours, among which control strategy, and ‘which variable affects which’. Moreover, pilot performance is preceded by their knowledge of situations in which multiple goals and constraints act in the work system. Bisantz et al. (2015, p. 66) found (semi-structured) interviews very apt to elicit such information, in particular when the interviews include what interviewees consider to be challenging situations and demands on their strategies applied to arrive to successful outcomes. I added these situations specifically with flight profiles and activity cards. With that in mind interviews were found appt to guide me in finding the previously mentioned critical work situations and work-as-done. To get the most out of it, I combined the interviews with observations, which are discussed below.

I used semi-structured interviews of approximately 90 minutes in which I covered a discussion on ‘iPad related activities and interactions’ during a whole flight in which I specifically looked for critical activities. These interviews were written out totally and used later-on to substantiate the human-artifact model according to the associated activity theoretical framework. At the same time, I probed about the cockpit ecological activities and duties, to eventually facilitate a discussion on teamwork as proposed by Klein et al. (2005). A semi-structured interview protocol was used (see Appendix D).

Unfortunately, it was not possible to join the flight deck on actual line flights, which would have really turned this study into an ethnographic study. Because of this, I included actual observations of the participants working with an actual iPad into the interviews. To this end, and to explore the broader range of activities taking place in flight operations than I could encounter on a small number of line flights, I developed flight profiles and activity cards. Guided by these visual aids, the participants were asked to walk-through a fixed set of critical flight phases. Whenever the participants found activities to be relevant during those flight phases, they were asked to tell and show how they actually work their iPads in those activities, which I could observe. The iPad was placed next to them in a similar position as in the cockpit Specifics about the flight profiles, activity cards and observations are described below.

Four main interviews were held in total. All the interviews were done in the native language. Only when cited, they were translated to English. Audio recordings were made, these were used to transcribe the interviews on a computer as quick as possible after the interview. Every transcript was sent to the relevant subject matter expert for verification of its contents. Furthermore, the researcher named the apps by their functionality instead of the commercial name.

Through the interviews, I attempted to attend to the ‘native view’ of pilots working with the iPad in the cockpit through their narratives, in which they tell what they do, and how they interpret particular situations or experiences. Through these accounts I tried to address both the formal and the informal logics of their everyday work (Vaughan, 2016, p. 77). A positive aspect in this is being a pilot myself. My domain expertise helped me probing effectively during interviews because it allowed me to actually capture the native view. With this experience, I could fill in, filter out, or probe for details that matter in the social world of piloting. A risk of this, however, is of course that I would bring in my own experience too much into the research results, conforming too much to the native view, considering what was being said as logical and normative, thereby limiting my capacity to notice when a meaningful conflict was mentioned. In that case I would have taken the native view too far, which is called going native (Bourrier, 2011, p. 14).

To prevent going native, I considered scrutinizing examples of similar research (Nemeth et al., 2011; Perry & Wears, 2012), and even more so, the theoretical foundations I drew on, and my formation at Lund to have provided me with enough baggage to avoid going native, and to develop meaningful interpretations of data with regards to risk and safety.

3.3.4.1 Flight Profiles and Activity Cards. Flight profiles (see Appendix A: Flight profiles) were developed to establish dialogue on the dynamics of flight because iPad related activities normally take place in a moving aircraft that is passing through flight phases. The flight profiles used represent a number of relevant flight phases. Interviews with the flight profiles started from off-blocks (which is when the aircraft leaves the parking position) and ended once the parking position was reached again after flight (on-blocks).

The activity cards (see Appendix B: Activity cards) represented relevant examples of iPad related (critical) activities during flight. These were extracted from the ASRs, complemented with activities that followed from studying a number of organisational documents about the iPad and the iPad's hard- and software. Aided by the activity cards, activities were discussed along the flight profiles during the interviews, during which the participants showed how they would actually handle their iPad in flight during these situations. The actions of the participants were observed and noted.

One activity card (de-icing) was pushed by the researcher and was used for a little activity related experiment. In this activity the iPad was used to perform a calculation for which the environmental variables were predefined.

3.3.4.2 Observations. The knowledge of work-as-done came about in this research through observations of the actual work practice in combination with the disclosure of information from the perspective of the SMEs. During the interviews, I managed to 'sense' (as in interpret) work-as-done through what the SMEs' were capable to share and what I was able to extract. However, 'what people say, what they do, and what they say they do' could be entirely different things (Bisantz et al., 2015, p. 70). Because of these inherent limitations, observations of pilots actually working with the iPad was added as a data source. Thereto the

SMEs were asked to bring their own iPad to the interview session. They were asked to illustrate, during the interview, what they actually do with the iPad in the cockpit JCS.

The (critical) flight phases derived from the documents and the activities developed during the artifact analysis were visually presented to the SME's by the researcher and discussed during the interviews (see Appendix A: Flight profiles, Appendix B: Activity cards). These functioned as an aid to perform a cognitive walkthrough, which is considered to be a strong way to evaluate designs in actual practice (Wilson & Sharples, 2015, pp. 270, 363), foster reflection and discussion, and facilitate probing (Glegg, 2019). It made it possible, as such, to discuss the iPad related activities and interactions against a structured background: the flight-phase and its associated responsibilities.

What the SMEs revealed during the interviews (e.g. by recollecting events, situations or habits) was regularly demonstrated on their iPads.

In general, the observations were articulated and directly recorded during the interview. I focused particularly on details that were not mentioned in words. Observations of complicated situations were jotted down and written out directly afterwards.

3.3.5 Informants

To select the informants for the interviews, the researcher called to mind multiple colleagues of whom he thought they could give a good reflection on the way work is done. Kept in mind was a pre-established relationship of trust (e.g. due to having worked together happily multiple times) and a conceived capacity to speak about 'what is going on' in our work domain. To bring in additional and relevant information about the historical transformations two pilots were sought and found because of their slightly longer experience with the paper cockpit. Pilots were consequently approached by e-mail for their willingness to cooperate in the research.

The informants, the group of Subject Matter Experts, consisted of both co-pilots and captains from my own organization, who fly short-haul flights in Europe. Both groups actually worked with the iPad[11] during their work, and have expert knowledge about the cockpit ecology they work in. Their experience is expressed by years in the organization as a pilot.

Informants were utilized for both the artifact analysis interview and the four main interviews. For the artifact analysis interview, two pilots were interviewed at the same time: one captain with fifteen years of experience and one co-pilot with seven years of experience. The four main interviews were conducted with one informant per interview. Interviewed were two captains, one with eight years of experience and the other with fourteen years, and two co-pilots, one with five years of experience and the other with seven years of experience[12]. A total of three captains and two co-pilots were interviewed. Each interview was written out totally.

3.4 Analysis

The analysis in this research was guided by the activity analysis as informed by the human-artifact model and JCS. Certain activities with the iPad that contained breakdowns and tensions were subject for analysis, as well as iPad related activities that (could) affect the

[11] Flights are executed with one captain and one co-pilot, the main difference between both is that the captain has final responsibility. The distribution of work depends on who is pilot flying or pilot monitoring, these roles are evenly divided. The pilot flying manually flies the aircraft or manipulates the autopilot, while the pilot monitoring performs radio communication and other tasks.

[12] The co-pilot participating in the interview for the artifact analysis was asked to participate in the interview for the activity analysis again, by that time the captain participating in the interview for the artifact analysis no longer worked in the same division and therefor was not asked again.

cockpit ecological level (all guided by the interview questions, the flight profiles, and the activity cards).

For transparency reasons, the analysis that was performed in each of the steps displayed in Figure 8 is described in detail below.

3.2.2 Artifact Analysis

The activity analysis of the human-artifact model in this research started with an artifact analysis. This artifact analysis included the study of ASRs, company documents about the iPad, iPad hard- and software, as well as one interview with two informants.

The aim of this artifact analysis was to understand what activities were introduced into the cockpit ecology by the iPad compared to the paper era. Because of this, the artifact analysis focused on the iPad, on what it does in the cockpit eco system, and the activities it introduced into the cockpit JCS that were not there before. As suggested by Erlingsson and Brysiewicz (2017) for analysis of content, (condensed) meaning units were derived about the main points in the relevant ASRs by dividing the text up into smaller parts, after which these units were developed into descriptive codes (Appendix G, Table A 1). The descriptive codes were complemented and refined with codes derived from the hard- and software analysis and relevant texts derived from the organisational documents. The results of this were discussed in an interview with two subject matter experts. Appendix C presents the questions asked during this particular interview. During the interview, some differences in work were recalled between the period before and the period since the iPad, which is referred at in this research as the ‘paper era’ (as opposed to the ‘iPad period’), hence the use of ‘iPad vs paper’ in Appendix G, Table A 3. The answers from the fifth question onwards allowed me to describe how the iPad is situated in the cockpit and how this would influence the pilot in its use. This could be in a direct sense, between pilot and iPad, but also on how the positioning would affect activities embedded within the larger cockpit ecology.

Operational features, such as the location of the iPad, what apps were used, and the manner in which these function and the pilots interact with them, were key in understanding the categories of activities that could produce additional or divergent(cognitive) efforts or require functional skills (Nemeth et al., 2011, p. 197) when compared to the paper era. These operational features were interpreted to themes and tensions to process into the protocol for the main interviews. This is in line with Winograd and Flores (1986, pp. 77–78), who argue that *breakdowns* in functioning can reveal “to us the nature of our practices and equipment”, and thereby the role of the mediating artifact. After the interview for the artifact analysis, a selection was made of what activities to introduce into the main interviews (Appendix G, Table A 2). To this end, the activity cards were re-evaluated and complemented for their relevance. Moreover, insight was gained on what (critical) activities the human-artifact model at the micro-level could be substantiated with.

3.2.3 Activity Analysis

The activity analysis built on the artifact analysis. Details on how this was performed has been described above. In this paragraph the remainder of the activity analysis is described. This includes first the analysis of the main interviews (both the verbal information as well as the observations) and from there, how this data completed the human-artifact-model and finally, how all this data was aggregated with the JCS literature for the purpose of answering the main research question.

3.2.3.1 Interview Analysis (Verbal Information and Observations). The activity theoretical foundation served as a hermeneutical foundation to interpret the activities with the iPad in the cockpit ecology, as described (and performed) by the SMEs in the interviews. The usefulness of the sensitizing phase and artifact analysis were not limited to the development of codes (including activities), they also helped guide the onward interviews and activity analysis in a very concrete way towards activities and flight phases prone to contain tensions and breakdowns.

The four main interviews were mainly guided by the activity cards. As a consequence, the information gathered from the interviews was rooted in specific activities. When certain data was mentioned/seen only once, it was still used for the analysis if it was found to have any significance (Cober & Adams, 2020).

Activity theory guided me scrutinize the activity by asking how (operational sequences), what (goal) and why (long term motive), after which meaning units were derived from the information gathered that then could be used to fill in the human-artifact model. Focussed was on those iPad activities that contained breakdowns in iPad related activities and in the cockpit ecology, these were noticed by:

- The SME expressing irritation, sharing negative iPad use experiences or labelling something as clumsy to work with and the effects on the activity
- SME sharing personal work strategies, transformations thereof and strategies developed to prevent breakdowns
- Interplay between micro and cockpit ecological level, especially when a clear impact on the cockpit ecological level was communicated
- The SME telling about transformation of activities throughout time and new activity introduction
- Identification of gaps between what was said and done (e.g., the pilot might just say a taxi chart is being opened, but practically used a several hand gestures to get it done)

The difference between work-as-done and work-as-prescribed can also be understood as a breakdown, These breakdowns might not be experienced as such by the pilots, but the artifact analysis (and part of the activity analysis) made it possible to treat these as types of breakdowns, therefore focus was placed on:

- Identification of gaps between work-as-prescribed and work-as-done as shared by the SMEs
- Identification of gaps between an activity as designed through the artifact and activity as performed or encountered by the human

From these pilot experiences and gaps between work-as-done and work-as prescribed, meaning units were derived, especially for critical flight phases. Those meaning units, pointing out breakdowns or tensions, were further condensed and used to fill in the human-artifact model in the following cases:

- When encountered on a regular basis
- When they point out aspects that are formally not acknowledged
- When the impact on the pilot (e.g. frustration) or the cockpit ecological level stood out

3.2.3.2 Aggregation into the JCS. The activities and their impact at the micro- and cockpit ecological level were processed to complete the human-artifact model as modified with the JCS hierarchical levels (Figure 4) to point out associated tensions, breakdowns, and ‘activity costs’. The analysis developed in this way an understanding of both the artifact and the human (pilot) (and their interrelation) in the activities, as well as relationships between the micro- and cockpit ecological level. To point out how certain activities historically transformed, a historical analysis of a goal-oriented activity was performed by analysing the activity with past artifacts (paper) and comparing the activity with the iPad (Bodker & Klokmose, 2011, pp. 355–357).

3.3 Rigor in Research and Data

"Generally speaking, quality refers to the transparency of the whole research process (Seale, 2007, p. 377)." For that reason, it was aimed for to be transparent about the research process to the extent that is deemed fitting for the purpose of the study. For this reason, the steps that were taken in this research process have been made explicit, as well as the methods used to collect types of data, the backgrounds of the flight profiles and activity cards that were used during the interviews, and the questions that were prompted during the interviews. Also, the rationality for each interview question has been given. I further have tried to address as transparent as possible all the (implicit) assumptions that I was aware of, the strengths and weaknesses of the methods that I used, as well as the way in which I think they complemented each other. For instance, as a researcher, I inevitably bring in assumptions to my research, not in the least because I am an airline pilot who has worked with the iPad himself. All these reflections have been discussed throughout my research.

The iPad has only been around in the cockpit for ten years and this artifact and its use has changed ever since. These transformations and adaptations and experiences thereof can be very personal and might not be applicable on a general level. However, this research was performed and written, not to tell per se what qualitative findings are generally applicable in a cockpit with an iPad, but rather for the reader to reflect on one's own work, as to allow this person to decide for oneself to what extent the findings are relevant and of interest.

Generalization of findings was not my first concern, immersion was. Thus, the data in this research was gathered and analysed to have practical significance primarily, not for seeking truisms. Because of this, I chose a labour-intensive research design that would provide depth rather than generalization. A small number of sources resulted in an exponential amount of data to analyse. Stopping the interviews on the basis of data saturation or the finding of repetitive patterns would have raised this research's analytical power but that was not possible within the restraints of this thesis, I judged it prudent though to stop interviewing after the fifth interview after having collected an enormous amount of useful data on activities, their interactions, and often unique use-strategies.

The methodology that was chosen was sensitive to pilots' subjectivity, meaning (or lack thereof), and activity that they would attribute to situations (Bornat, 2007, p. 41). Nonetheless, care has been taken to deliver rigor in this research regarding this issue. I already described how I have tried to be as transparent, consistent, and systematic as possible in the choices I made, my possible biases, the data sources I used, and the actions and analysis steps I performed during the research. All this helps in the replicability of my research. Apart from that I applied the following strategies, that contribute to credibility, transferability, dependability and confirmability (Anfara et al., 2002, p. 7)[13]:

- *Triangulation* of data sources that consisted of air safety reports, documents and interviews that included observations throughout the research. Triangulation helps in checking the findings from one data source against those of other data sources. This increases the credibility of the research and dependability.
- The use of SMEs, who were selected in such a manner that they had the occupational background needed to provide meaningful information. Their ability to convey this

[13] Anfara, Brown and Mangione proposed alternative concepts to judge qualitative research. Credibility represents internal validity, transferability represents external validity, dependability represents reliability, confirmability represents objectivity.

meaningful information on the use of the iPad was also considered before inviting them for the interviews. They (and their experiences) served as specific units for analysis. This approach is called *purposive sampling* and in Anfara et al. (2002) can be seen as a way to contribute to transferability.

- Creswell describes qualitative research as interpretative research (2009, p. 177). Practicing *reflexivity* during this research meant that I reflected on how my interpretation was influenced by both my personal (e.g. occupational) background and the research design, this included recognizing strengths and weaknesses of methods and acknowledging what sort of results were valued. Anfara et al. (2002) indicate reflexivity as a strategy to acquire confirmability. Throughout the research I injected reflections on my background and possible biases.
- *Prolonged engagement in the field as a researcher,* is a way for the researcher to develop an in-depth understanding of what is studied. According to Creswell "the more experience that a researcher has with participants in their actual setting, the more accurate or valid will be the findings." On the other hand, and as previously mentioned, the researcher that is engaged in the field can also lose distance and 'go native'. Mentioned was how this was mitigated by approaching 'the field' as an academic, while being 'a native'.
- Peer examination is indicated as a way to acquire dependability (Anfara et al., 2002). The transcriptions of the interviews, as well as the thesis results were sent to the SMEs and feedback was asked. The thesis furthermore has been offered for feedback to the thesis supervisors in several stages of the study.

3.4 Research Ethics

Regarding the involved organisation, I performed interviews in one specific division for which I have asked and was granted permission. If my investigation reveals weaknesses in the airline operations due to the iPad introduction it could come at a cost for my organisation. For that reason, but also because of general scientific principles, I kept the organisation's name and iPad applications anonymous.

On the individual level, participants of my study did not get any compensation. Their involvement was on a voluntary basis, and they could withdraw any time they wanted. This possible withdrawal was accompanied by the possibility to place a request to delete any of their contributions or processed data thereof after their participation, up until the moment I would start the analysis. This cut-off moment was chosen because from that moment on the data was anonymised, making it impossible to filter out which data was whose. For confidentiality and privacy reasons, I stored their contributions on my PC to which only I have access. I did not relate to any participant in any recognizable way. After the completion of my study, I will delete the audio recordings. Before every interview, the participants were briefed about the aforementioned considerations, both verbally and in a written form. They were also informed about the reason for this study, about what I would do with the results, and the duration of the interview. After giving them a chance to ask me questions, they were asked to read and sign a consent form by which they agreed to proceed (Appendix F). The consent forms were kept in a special safe.

4 Findings

The results are presented from inside outwards, focussing on the iPad, on iPad related activities that take place and then, on how they interact in the JCS as a whole. To apply the activity theoretical approach, these findings are related to the human-artifact model in some paragraphs. Paragraph 1 focuses on the findings from the artifact analysis, which included interviews with subject matter experts on some relevant technical features of the iPad device. Paragraph 2 moves outward and discusses technicalities and formal (prescribed) use of the iPad in the cockpit ecology. It explores relevant issues regarding the iPad location as well as its role in the cockpit ecology. It also discusses the way in which the artifact has formally been conceived. Subsequently, focus is placed on the pilots who operate the iPad (4.3). Discussed here is the activity analysis, which includes the discussion of various activities with the iPad in the cockpit, as well as some historical transformations of the iPad. Breakdowns at the cockpit ecological level that can be related to iPad use have been explored here also. In the last paragraph (4) of this chapter, the consequence of the iPad as source of messiness is dealt with in relation to the aircraft environment and the way pilots learn to use it. Informant citations have been added in italics throughout the findings for illustration purposes.

4.1 Artifact Analysis: The iPad as Imagined Versus the iPad as it Behaves

During the artifact analysis the ASRs informed me about the way in which pilots were confronted by doing work with the iPad. I also learned about flight phases this occurred in. Reported in the ASRs was that information was missing, that the iPad ‘acted’ by itself moving pilots to troubleshoot the device, and that difficulties were encountered to manage the iPad’s functionalities and content. In several cases, work with the iPad was reported to propagate into (flightpath) deviations that caused aircraft warning systems to activate. The interview produced insight into the many possible activities by and with the iPad. Therefore, to start by, this paragraph resulted in a tour on "iPad-messiness" in which it becomes clear that it is difficult to conceptualize the iPad as something that 'is', as something fixed and stable. This will be made clear, first by illustrating irregularities in its behaviour, then shortly by discussing the limited and problematic formal conception of the iPad, which is followed by a discussion on the contradictions that emerge during interaction between design functionalities in the iPad and user interactions with the iPad.

4.1.1 Digital Fluidity

The iPad, because it is a digital device, cannot be compared to a tool that has a stable form like, for example, a hammer. An iPad changes over time due to both soft- and hardware changes that influence how pilots bring their knowledge to bear and their capacity to retrieve it. The software and hardware changes are one way of showing that the iPad is continuously transforming, and thereby acts as an agent on itself. This is all the more so because it is not subject to the usual aviation regulation (because it is an off-the-shelf plug-in asset not belonging to the certification of the aircraft), because of which it is updated regularly (regarding software and hardware) according to its own schedule.

The most common changes on the iPad are *software updates* that can change the iPad's behaviour. These software updates can be summarized as changes that operate on three levels; on the level of the operating platform[14], on the level of applications, and on the level of in-application content. During this research two applications, regularly used during flight operations, were updated. The updates changed the location and layout of information on the

[14] Fourteen operating platform updates were introduced in 2021 (*Apple Security Updates*, 2022), application updates are less regular. The in-app content updates are required before every flight cycle, one application needs an update on a daily basis, other applications require an update before every flight.

iPad, as well as the way information can be retrieved. Some effects of these changes will be treated in this research.

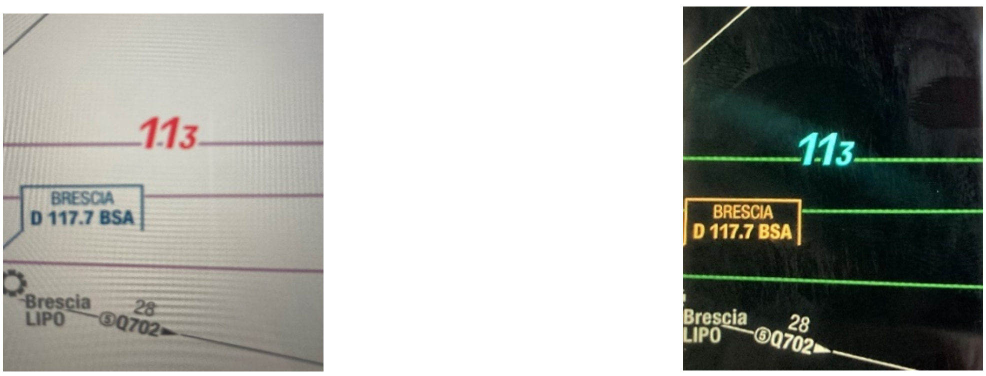
Many *hardware changes* of the iPad have also occurred since its introduction. During the artifact analysis interview it was mentioned that spare memory on the iPad became an issue as well as its speed. Also, newer iPads were distributed to pilots. One of the interviewees was still using an older iPad model that is smaller than was common at that time and adds to the constellation of possible iPads.

4.1.2 Glitches, Irregularities and Unruliness

The internal iPad functionalities and layers of software sometimes lead to inconsistencies and contradictions in the represented information. During the artifact analysis interview two examples of this were mentioned. The first came about while discussing the activity card on screen brightness and dark mode. The map-legend states that the minimum grid altitude (an altitude to stay clear of terrain) is coloured red when at or above 10.000 feet. The iPad however can be configured to a mode that it represents the colour in blue (Figure 9), which is not congruent to the documentation.

Figure 9

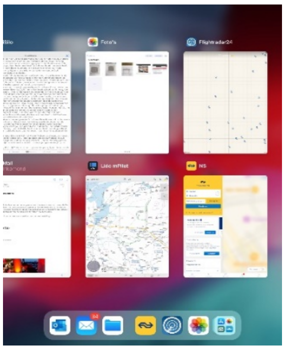
Screenshot: Numbers changing colours due to internal iPad configurations



The second example is given in Figure 10. The iPad offers a shortcut that gives an overview of six snapshots of recently opened apps. When discussing glitches during the artifact interview, mention was made of occurrences in which the data depicted in the 'six apps overview' was old and wrong. This inconsistency has been encountered during work conditions when pilots used this shortcut to check the necessary thrust target for take-off,[15] in which case this shortcut may provide pilots with wrong and unsafe information.

Figure 10

Screenshot: Six apps in one screen (as snapshots) of recently opened apps



During the five interviews, one for the artifact analysis and four for the activity analysis, the SMEs[16] reported furthermore on what they experienced as (ir)regularities in the iPad's behaviour besides the hard- and software changes. Most irregularities they mentioned were discussed as 'glitches' or problematic iPad behaviour[17]. These behaviours consist of (but are not limited to):

1) Ask the user to login (…again, on unexpected moments)

2) Crashing apps

3) Ability and time required to connect to a mobile network

[15] In the examples above, common sense and trouble shooting would prevent pilots to be mislead.

[16] Numbers 1 up to and including 12 were found in ASRS as well

[17] For that reason, for the activity theoretical perspective, I consider glitches to have no motive, they are not present in the iPad by design but 'by accident'.

4) Automatically increase or decrease brightness

5) Discharging of battery

6) Enter into night mode

7) Automatically shutting down

8) Ghost touches [18]

9) Missing or incomplete information

10) Unresponsiveness (slow iPad or ‘frozen’ screen)

11) Buzzing sound when charging and holding the iPad

12) Prompting a password reset

In addition, the ASRS showed:

13) Shutting down due to overheating

14) Smoke and fire

15) iPad entering sleep mode

4.1.3 The iPad as a Dynamic Agent

The analysis in this paragraph provides examples of how the design of the iPad is underspecified and unrepresentative for what the iPad at times delivers (or is), and thus for what the iPad sometimes does. It also illustrates how the agency of the iPad can create complexity, i.e., by introducing a certain amount of messiness in work (C. Nemeth, Cook, &

[18] Ghost touches refer to random changes, e.g. the sudden change of applications or charts. SME’s mentioned this phenomenon was observed in the past, with a mounting device that is no longer in use, while charging.

Woods, 2004). Understanding this is necessary to understand working with the iPad in the cockpit ecology in a fuller dimension than can be done by analytic decomposition alone. Per design, unforeseen activities take place in the configuration of the iPad, in the form of glitches, or in such a way that the iPad represents ‘unruly information’ and may even present misleading information. One should consider, in other words, that the particular features of the iPad are able to create a gap between the idea about what you think the artifact will do, and what the artifact actually does.

What the analysis in this paragraph illustrates, is how the iPad in some cases acts, according to the informants, as an agent ‘on behalf of itself’[19] in the realm of flight operations. Interviewees mentioned, for instance, how the iPad can disrupt the conventional way a pilot works at unexpected moments while discussing the ‘glitches’ activity card. *“Yes that you then have to change it [the password] just before departure and that otherwise you just can’t access your information anymore.”* Another interviewee commented: *“Yes, last time the flight plan-app blocked during taxi-out.”* The point here is that these often unexpectedly induced behaviours of the iPad are, or have been, experienced as operational facts in which pilots feel subjected to iPad behaviour. Not only does the iPad, with its variable use possibilities, participate in the future constellation of operational configurations, these transformations also introduce new constellations and configurations of use in the cockpit JCS. For now, it suffices to mention that pilots that work with the iPad must be aware of the fact that they continuously have to bring (newly) packed knowledge to bear in a changing system that has inner complexities, irregularities and glitches. Normally, when irregularities present itself in conventional technology of an aircraft, emergency checklists are developed and consulted, or the technicality is recorded in a technical logbook after which troubleshooting occurs. In the case of the iPad, however, the iPad leaves no such option

[19] In this study the unit of analysis deliberately leaves out the agents that develop and transform the iPad

because this type of technology is allowed to have a moulding nature with hard- and software updates to get the most out of it. It does not rely on extensive test & evaluation and standardization programs and strict maintenance processes. The iPad instead has 'pilots' to solve problems and its resulting irregularities in flight management.

What all this points out is that this severely complicates the creation of the artifact column in the human-artifact model. With the iPad, the 'how and what level' in the artifact column does not consist of static data, it rather changes over time by design or by irregularity.

4.2 Situating "the" iPad in the Cockpit Ecology

This second paragraph in the findings chapter starts with a description of what the informants reported about the role of the iPad in the cockpit. After that, it discusses findings regarding the location of the iPad in the cockpit, and the experiences of pilots related to that location. The paragraph ends with a description and critical discussion of the formal rules in the organisation on how to use the iPad in the cockpit[20] by means of the human-artifact model (work-as-prescribed).

4.2.1 A Cognitive Artifact

Artifacts that are developed to be used professionally 'are representations of what matters in this work domain' and 'their content is inherently connected to what is meaningful in the domain' (Nemeth & Cook, 2013, p. 305). This also applies to the iPad. In addition, Nemeth and Cook (2013, p. 305) mention that such artifact 'conveys the information in a compact, efficient manner'.

[20] During the predefined flightphases that are focused on in this research.

The organisation requires eleven apps to be installed and used by the pilots. These applications aim to improve the cognition of the pilots in different ways. Especially six[21] of these eleven organizational applications (apps) have been found to be used by pilots during their flights. Mostly three of these apps have been discussed at length with the informants and delivered the most relevant information for this study. The charts-and-manuals-app contains information about airport layouts including facilities as parking positions, approach information and relevant radio frequencies, as well as all relevant documents and manuals that are distributed to the pilots. The performance-app is designed to inform both pilots and aircraft (through pilot input) of the necessary thrust and speeds at take-off and landing. The flightplan-app contains information relevant to a specific flight such as routing and necessary fuel at certain points enroute, amounts of fuel, weather, airspace and airport news[22] items.

The iPad apparently plays a central role on informing pilots in both prescriptive and descriptive ways about (what to do in) their complex work environment, e.g. it provides information that prescribes how to fly a certain procedure and it describes airport layouts with certain highlights that are to be considered when operating there. In that manner, the iPad adds value to the pilots' work and cockpit ecology. The iPad can, in this context, in the sense as discussed in this paragraph be called a passive cognitive artifact. It holds certain cognitive elements within the larger JCS for the pilots to retrieve.

4.2.2 Ergonomics of the iPads in the Cockpit

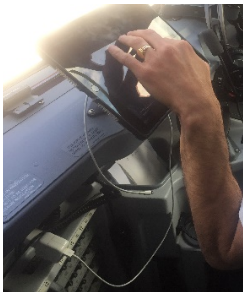
The pilots usually plug-in their iPads by fixing it in the cockpit on the lower section of the left and right window frame. Both frames have a mount, in general slightly below

[21] Other non organizational apps were mentioned as well but not treated in this research.
[22] In aviation the news items are called notams, this stands for notices to airmen.

shoulder height (when seated). The iPad can be placed in the mount by 'clicking' a special iPad-case into a locking mechanism that can be rotated freely on an ball joint.

Figure 11

Location of iPad in cockpit and hand positions



Note. iPad in lower left window frame operated with right hand by left seat pilot (left), example of 't-rex claw' when using the left hand and having the charger plugged in (right)

Since the aircraft was developed without the iPad, the implementation of the iPad was not foreseen by the aircraft developer. The iPad therefore has not been nicely integrated into the cockpit but placed somewhat to the side. From all interviews, four out of five pilots expressed some form of criticism about the iPad locations. Retrieving information from the iPad occurs with hands and eyes. The interviewees in the artifact analysis agreed that *"for right-handed people it's more convenient to sit on the left [seat]…"* since using the hand nearest to the iPad mount would require handling it with a *'T-Rex claw'* (Figure 11). This experience of discomfort, also due to having to turn sideways to read the screen, is part of normal handling of the iPad, which becomes especially discomfortable when it comes to a longer continuous use period: *"if I'm going to read I often take it out [of the mount] and then get it in front of me"* to avoid sitting *"in such a difficult curve"* for an extended period of time. It was furthermore mentioned that the present position of the iPad made it hard to retrieve information easily. When you would have it in front *“you [could] aim just fine with your finger on the pad”*.

According to the informants, the position of the iPad not only places a burden on the pilots’ hands and body, but also has visual consequences. When asked, for instance, why placing the iPads more forward would be better one of the informants answered: *“because you don’t have to look sideways as much, and the less you have to look sideways for your [iPad] screen, the more you see the rest of the cockpit which of course is important too”*. Another answered: *“ideally having it [the iPad] under a smaller angle”* to be able to scan the cockpit instruments quicker, *‘’I now have to consciously turn my head 90 degrees to see”*. Not seeing the other pilot while operating the iPad, and thus not being able to see possible non-verbal communications from the other pilot, was mentioned as well. What the informants did regard as an advantage of the current iPad position is that they perceived having a screen nearby as *“pleasant”, “because that way you don’t have to zoom in super far, and you can read everything clearly*.” This does not mean though, that information is directly readable. In the majority of cases, activities with iPad charts during the interviews were observed to be accompanied by a zoom gesture and to a lesser extent by dragging the information so as to position it well in the screen. Information on the iPad, in other words, generally has to be manipulated to be readable on the screen.

Table 2 presents the human-artifact model for aspects of the iPad location. The subject matter experts indicated that activities with the iPad can be cumbersome and that, at the cockpit ecological level, it interferes with their attendance to the cockpit instruments. The red exclamation marks in the table point out *at what level* tensions were experienced, related to the iPad location and use, in the cockpit ecology. The lightning strike symbols in Table 2 point out *between* what levels tensions have been mentioned, in this table the lightning strike symbol in the cockpit ecological level originates from iPad related activities. Table 2 also includes the glitches and problematic behaviour mentioned in paragraph 4.1.2 that can impair the depiction of information. This is preceded by a yellow 'not designed for': to draw attention to something that conceptually should not, yet is, present in the artifact.

Table 2

Human-artifact model with data from the artifact analysis for the artifact location, pointing out possible tensions

Cockpit ecology	Pilot		
Controlled flight	Control flight	iPad	Pilot
Represent aircraft status and control aircraft	!! Have hands and eyes on cockpit representations and controls !!	Facilitate information for flight, enter information	Find/enter relevant information related to flight or work.
Flight instruments, flight controls and interact with colleague	Scan and modulate instruments/ controls and interact with colleague	Depict information Not designed for: glitches and problematic behaviour (see 4.1.2)	Read/ Retrieve information
		Interact with fingers and eyes	! Turn head and body in curve, t-rex claw, zoom in, place eyes on screen !

4.2.3 Formal iPad Use – Work-as-Prescribed

Before we can proceed to issues of work-as-done with the iPad, it is necessary to describe the formal rules of how to operate the iPads in the cockpit, work-as-prescribed. Three organizational documents[23] communicate about formal use of the iPad. From a human-artifact model perspective, this amount of formal documentation to communicate on a device that is so central to flight management is minimal. This suggests a wide gap between work-as-prescribed and work-as done, because few work prescriptions leave more room to operators to

[23] Basic operating manual, flight safety manual and minimum equipment list

fill in their discretionary space, especially when, as in this case, activities with the iPad are frequent and extensive and changes are every day's business.

In line with what has been laid down in chapter 3, the description on work-as-prescribed in this section, will remain limited to the focus of this study, to those flight phases that have been defined as high workload and critical phases.

4.2.3.1 Misalignment with Formal Documentation. Documentation and regulation are oblivious to the thirteen use aspects that were referred to in 4.1.2, which the pilots regarded as glitches and irregularities. The formal documents regulate when the three levels of software updates are to be performed. However, these regulations, do not include making the pilots aware of how systemic changes such as these kinds of updates alter the way knowledge is packaged, delivered, transmitted and stored (Woods et al., 2010, p. 140), and thus about how these kinds of changes actually influence their work.

4.2.3.2 Work-as-Prescribed According to Formal Documentation. The documents prescribe a 'sterile cockpit' to be maintained by flight crew during critical flight phases. This, among other things, must be done by refraining from activities that could interfere with the proper conduct of cockpit duties. Using the iPad, however, as we will see, is regarded an interference at times by the pilots, while the iPad has to be regarded, at the same time, as part of the work.

Documents mention that pilots must 'be alert and maintain situational awareness' during all activities. It also directs the pilots on duty to normally let the pilot that is not actually steering the aircraft (the pilot non-flying or PNF) use the iPad, while another sentence states that the pilot flying (PF) can use it when workload allows. What is meant by 'normally' is not specified. Pilots are also instructed to keep the interaction with the iPad minimal during phases of high workload. What is meant by 'minimal' is not specified either. At the same they are required to use the iPad during phases of high workload, e.g. by keeping track of the aircraft position on the airport diagrams. These restrictions on iPad use can be read in light of the documentational acknowledgements that iPad activity poses a threat to primary flight duties, and somewhere else is written that its use must be ‘with consideration to threat of distraction and safety critical tasks’. Pilots are therefor warned by the books to avoid fixation on the screen and distraction from primary flight duties while using the iPad. What makes this form of work-as-prescribed problematic and debatable is what Billings (1996) mentioned as the lacking capacity of documents to refer to internal relationships and interdependencies. The consequence is that it is not clear ‘when’ certain limits on iPad use are reached or applicable. In other words, the use of the iPad can be part of distraction without one realizing ‘it is a distraction’.

These, and some other aspects of work-as-prescribed with the iPad, especially in relation to the critical flight phases, have been taken up in Table 3, in which this formal use of the iPad is juxtaposed in the human-artifact model with data delivered by the SMEs during the interviews about work with the iPad. What these interviews showed is that the extent to which work-as-prescribed is, and can be, adhered to is debatable. This can be seen in Table 3 by means of the colours. What is written in black in the right column of both JCS levels is what has been found to be adhered to, what is red has been found not to be adhered to, amber stands for problematic and debatable. The numbers in the table are added to correlate the data on one side to the juxtaposed data on the other.

Table 3

Human-artifact model with summary of formal limitations on activities with the iPad on artifact side, in relation to cockpit ecology activities

Formal Cockpit ecology (sterile cockpit)	Human
15 Controlled flight 14 Maintain situation awareness	15 Control flight 14 Maintain situation awareness (partially)
13 Limit intra-flightdeck communication to what is necessary 12 Transfer controls as pilot flying when using iPad for extensive period 11 Pilot flying use of iPad only when workload allows 10 Apps not relevant for flight not allowed 9 Progressively follow position on airport diagram	13 Intra-flightdeck communication is necessary and increased 12 No transfer of controls + iPad use can become extensive period while in use 11 Pilot flying use of iPad only when workload 10 Apps not relevant for flight, can be rationalized as relevant and used 9 Progressively follow position on airport diagram, some skip it.
8 Stow loose articles 7 Normally pilot not flying operates iPad	8 Loose articles 7 Both operate iPad

Formal iPad	Human
6 Safe iPad use, so flight does not 'suffer' from iPad	6 Find or enter relevant information related to flight or work
5 Minimum iPad interaction during high workload 4 Don't use GPS 3 Avoid fixation on display 2 Avoid distraction from primary duties 1 Any malfunction influencing flight ops, call company department	5 iPad interaction during high workload 4 use GPS 3 (Avoid) fixation on display 2 (Avoid) distraction from primary duties 1 Many 'malfunctions' influencing flight ops (slightly) occur, and are solved by pilots
	Eyes and hand/fingers

4.3 In the Cockpit - Activity Analysis

Since my thesis relies on the assumption that the type of explanation for accidents would be similar to that of 'normal' performance (Hollnagel, 2012, p. 203), I will continue by discussing how the informants expressed, during the interviews, how they interact in practice with their iPads in a variety of activities. For this purpose, activity cards that were produced by means of the artifact analysis (Appendix G) were complemented by flight profiles to serve as visual means to help the discussion about a certain activity during the interviews. The flight profiles allowed each activity card to be envisioned for its relevance along the critical flight phase it was discussed against. This was done because Woods (2019, p. 2,3) pointed out that technology makes new demands on the practitioner that tend to congregate at the higher tempo or higher criticality periods of activity. Regarding information management on the iPad, for instance, the interviewees mentioned that zooming in at times removes relevant information. This issue can concern any information on the iPad. In one example however, a box containing a text with a warning shifted off the screen.

The discussion of all critical flight phases identified would be too extensive for this research. Chosen therefore is to focus on five issues: chart management during taxiing, chart management after (unknown) software updates, passing transition level, calculations for de-icing, and charging.

- Chart management during taxiing (4.3.1) proved itself as having the most 'meat on the bone' for this research during the interviews. The actions performed on the iPad during taxiing, and how this interacts with other activities, could be relatively easy presented and monitored in the interview setting. This is probably because taxiing takes place in a relatively disconnect of information on, for instance, the flight instruments. Within the critical flight phase of taxiing, it has been chosen to focus on two distinct activities, namely the retrieving and checking of airfield charts. Discussed specifically around these activities were the actions that pilots performed on the iPad and the tensions they experienced in relation to the iPad and cockpit ecology. During the interview, as has been explained in Chapter 2, activities were actually performed on the iPad by the interviewees. Focused primarily was both on these observed and the mentioned aspects of the messy work dimension. The iPad as artifact that is updated on a regular basis has been dealt with in Chapter 4, Paragraph 3.2. Since it was identified that the manipulable information landscape on the iPad screen introduced new forms of work, and finding the transition altitude was mentioned to be one of the first reasons to consult the iPad after take-off, focus was also placed on how activities associated with passing the transition altitude evolved throughout time in Paragraph 3.3.

- That new ways of presenting information can propagate from the micro level to the cockpit ecological level, was shown through an experiment on calculating protection times after de-icing (4.3.4).

- To create a broader understanding of the many activities that are introduced along with the iPad, ‘charging’ (4.3.5) was chosen since it contained some intricacies and because it was mentioned in every interview as something that takes place during taxiing (and other flight phases).

The chapter ends by acknowledging the complexity that iPad related activities introduce and (can) propagate into the cockpit ecological level, as has also been confirmed by some ASRS. The implications of this for the cockpit ecology as a whole (including “the other pilot”, “the cockpit”, and “flight”) have been elaborated upon in 4.4.

4.3.1 Chart Management During Taxiing

Chart information management is a skill that takes place during taxi and other flight phases, also at low altitudes[24]. Moving from one chart to another mainly happens during taxi-out, lining up on the runway, departure and during arrival, approach and taxi-in due to the transition from one flight phase to another.

[24] E.g. an altitude of 400 feet was reported by one interviewee, another one mentioned ‘after gear-up’ which is a couple of seconds after the aircraft lifts of from the runway.

4.3.1.1 Taxiing. Taxiing can only be done by the left seat pilot who is, in the organisation and aircraft discussed here, the captain. Work-as-prescribed requires cockpit crew members to have an airport diagram (which is on the iPad) readily available during taxi and to progressively follow the position on that airport diagram. According to the operating manual, the taxi route must be coordinated verbally between the cockpit crew members. The left seat pilot, for instance, calls out the route he is taking, which allows the other pilot to suggest corrections and to stay informed on future decisions. The informants confirmed that the coordination of the taxi route actually happens according to these procedures. The coordination of information retrieval from the iPad during taxiing, however, is not formally specified. Interviews provided more insight on how this aspect was integrated in this particular activity.

Taxiing happens after a taxi clearance[25] is received. It is not uncommon to receive multiple clearances on where to go next during taxiing. These require, both formally speaking as well as practically, the consultation of the airport diagram on the iPad. In this research, all the subject matter experts interviewed mentioned that although the iPad is needed in this way for taxiing, they at the same time thought that use of the iPad conflicts in one way or another with the actual taxi activity.

Every interviewee stated that iPad use during flight (including taxiing) is not coordinated between crew members in the cockpit JCS. It was also reported that simultaneous consultation of the iPad to decipher what a clearance entails must be seen as a normal phenomenon during flight and taxi phases.

4.3.1.2 Effect of Chart Retrieval on Taxi Accuracy. One pilot often saw colleagues '*zealously rooting around in the iPad*', after vacating the runway while continuing to taxi to

[25] A clearance is a message from air traffic controllers in which they verbally authorize aircraft to progress with a certain movement.

the parking position. Familiarity with the airport was mentioned to reduce the interaction with the iPad for reference. Without exception, the pilots interviewed for this research have seen pilots zigzagging the aircraft around and deviating from the centreline due to interactions on the iPad by the captain who was steering the aircraft. Answers varied from *"yes, but not regularly" to "multiple times in a pairing (consecutive days of work together)" to "Yes! sure"*. One of the pilots stated: "*I see a lot of captains do this (he looks at iPad and puts his hand on it as if he's working on it) and then ee, while they're driving in that direction at 30 knots and then ee looking off to the left. Yeah, like, where am I, you know, and then they search and then take a look [outside] and then [go] back to the centre [of the taxiway]"*. Why the iPad interactions are not left to the pilot who is not steering the aircraft while taxiing can be attributed to work-as-prescribed: it does allow both pilots to use the iPad, and actually requires each pilot to have the airport diagram readily available and progressively follow the routing on the airport charts.

4.3.1.3 Possibility of Not Using the iPad for Chart Retrieval During Taxiing. When asking a captain if he learned anything from working with the iPad, during taxiing for instance, he mentioned that he reduced the overall use of the iPad in the taxi-activity, as he became *"more and more aware that it is very distractive at certain moments"*. The zigzag experiences made him decide to reduce his iPad interactions by relying on the co-pilot (+iPad) more. However, even with this solution, he reported, it would still be common to perform operations on the iPad to double check the taxi-chart against the co-pilot's insights, which is done to ascertain both pilots have the same understanding of what their clearance entails.

4.3.1.4 Observed and Reported Breakdowns in iPad Handling During Chart Management when Taxiing. For chart management, the right app has to be opened, the relevant chart has to be opened, and the relevant information must be retrieved. Different operational sequences can be used to open the right app. In case another app than the chart app is opened, the following three operational sequences (how level), were mentioned to open the chart app. Pilots were observed to use different strategies but each was related to a possible breakdown.

1) The home button is pressed to exit the other app, the chart app is found on the main screen, it is opened and the app is being loaded by the iPad.

   Observed breakdown: Another finger touched the screen, thereby opening a different app then planned.

2) The pilot swipes (placing four fingers on the iPad) from the other app to the chart app, this operation toggles between apps that were opened before.

   Reported breakdown: The desired app was regularly reported to be lost in the swipe sequence, other apps would open except the app that one looked for.

3) By double tapping the home button, six apps come available from which the chart app can be chosen.

   Observed Breakdown: A lot of quick consecutive (mistaken) tapping on the home button happened to arrive at the desired app. Instead of a double tap, the home button was observed to be triple tapped, then a double tap was performed again followed by another triple tap. After one more double tap the pilot was able to open the right app was opened.

These breakdowns indicate that a mistake is easily made when handling the iPad. The iPad does not correct the breakdowns, because of which the pilot must perform more operational sequences than planned to open the right app after a breakdown. After opening the chart app, retrieving the relevant information forms another activity. Because of that, new operational sequences can be observed once the chart-app is opened. Pilots normally retrieve and arrange charts on the iPad in a clipboard during low workload moments (see Figure 12)[26] from where the pre-arranged information is managed. This is not part of work-as-prescribed. The pilots reported different strategies for this:

1) The pilot taps on a rectangle in the clipboard (Figure 12) to select the desired chart to activate it and then starts to interact with the information, e.g. zooms in (by placing two fingers on screen and spreading them apart) and drags the relevant information into the display.

   Reported Breakdown: tapping the wrong chart on the clipboard.

2) The pilot taps the left or right side of a digital 'button' in the lower left corner to select the 'next chart' to activate it and then starts to interact with this next chart. When the chart is in the extended mode, with the space for the clipboard used for the chart, this is the only way to move between charts.

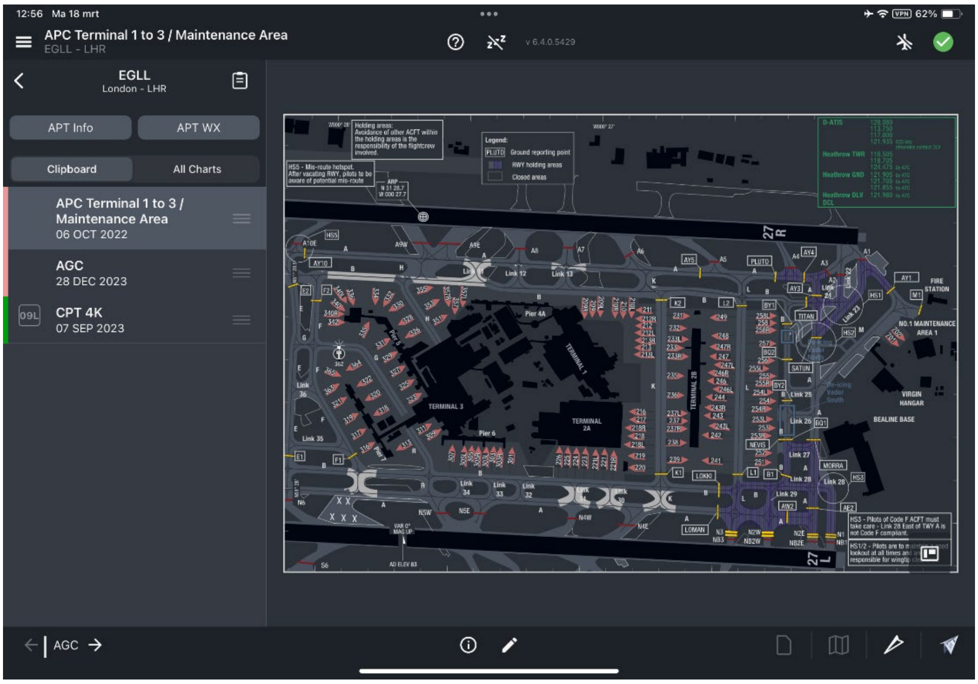
   None of the interviewees reported to use this strategy. However, during the interview, a 'second story' was told of a pilot who used this function and had to tap the button *'sixty times [not literally]'* until it responded successfully.

The mentioned and observed breakdowns point out the open-endedness of iPad related activities, that can place unexpected extra demands on unexpected (and possibly unwanted) moments on the pilot and the JCS.

[26] In this discussion the chart app is assumed to have opened in the 'chart mode', with all charts pre-arranged in a clipboard.

Figure 12

Screenshot of airport chart with clipboard on the left



Note. Example of chart mode (airport chart) with clipboard on the left that contains tiles to select other charts (e.g. AGC/ CPT 4K). The lower left corner shows two arrows that allow another way to go back and forth between charts (left) that are selected in the clipboard. These remain in sight if the clipboard is removed to make place for an expanded airport chart.

4.3.1.5 Wrap up of Findings on Cockpit Ecological Level after Activity Analysis:

Chart Management During Taxi. When taxiing, the use of charts is necessary but a risk at same time. During the 'paper era', before the iPad introduction, a taxi chart was placed on a (materially mounted) clipboard. The paper charts did not have to be switched on, login was not required, and information was fixed on the sheet of paper, it could not be 'dragged, zoomed and swiped'. Paper was simple compared to the iPad. Operating the iPad, because of the digitized features, introduces a more interactive iPad consultation that contains many breakdowns. These can even increase after updates that affect its handling, and as discussed in Chapter 4 (Para. 1.3 and 3.1), are not announced. Such breakdowns are especially precarious in critical flight phases such as taxiing because it takes time to correct the breakdown and to adapt to new handling strategies, while critical flight phases indicate periods of flight where time may be sparse and workload high, while surely information is necessary during that period. All pilots interviewed have seen their aircraft zigzag while taxiing, due to iPad consultation. An interference apparently lurs between 'steering the iPad and steering the aircraft', thereby indicating that micro level activities interfere with the activities at the cockpit ecological level. Three out of four subject matter experts shared their scenario's during the interviews:

1) After a long workday, the aircraft landed during darkness. The captain heard about a new parking position as the aircraft was rolling out on the runway. While vacating the runway at an exit that initially looked like a high speed exit a sudden sharp turn was required to follow the exit and continue onto the taxiway. The captain consulted the iPad while taking the exit. Manipulating the iPad to get the information required more effort than expected. The captain saw the edge of the exit approaching rapidly through the side-window. A quick correction was made by steering the aircraft back to the centreline.
2) While the crew had to follow an unfamiliar taxiway to make a u-turn, the captain and co-pilot consulted the iPad at the same time to find out what taxi-lines they were supposed to follow. While the captain initiated the turn blindly (while looking into his iPad), the aircraft continued straight ahead towards the grass. It took longer to respond to the situation than would normally be the case, due the iPad activity. The aircraft was stopped, there was a temporary nosewheel steering problem.
3) The co-pilot was starting a second engine during taxi-out, having his head down (instead of looking outside), focussing on the engine instruments. The captain engaged in iPad activities. When the co-pilot looked up he saw another aircraft opposing them, he shouted: stop! The captain stopped directly. The other aircraft stopped as well.

Table 4 makes the interactions with the iPad during the taxi activity explicit with the human-artifact model (see 2.2 and 3.2.2/3.2.3) that was filled in based on what was mentioned and observed during the interviews about iPad use during taxi operations. Normally, the kinds of actions and goals involved in this combined activity remain implicit. Noting them in the table makes them explicit for the reader. In the table, the exclamation marks in red point out tensions and breakdowns, while 'not designed for' (in yellow) points out aspects of the iPad that are present in the iPad. What is important here is that the informants report that using the iPad can severely interfere with the taxi activity but that they also report that they feel that using the iPad during taxiing is necessary because it holds the airfield layouts, and that they thus actually tend to use the iPad quite often during the taxi phase, despite the risks it brings.

Table 4

The human artifact model for the micro level chart management activities related directly to taxiing

iPad	Human
Depict ground chart (+information)	Find and cross check taxi route and related information
Display ground chart	Use ground chart
Zoom in/out, swipe, drag, tap, variable 'window' size, (un)presented clipboard ! New handling features ! ! Changed information density ! Not designed for: unresponsive app, 'veiled' info (not presenting a chart in its total)	- Progress through charts by index clipboard (consequence: less space for chart depiction). - Zoom in (to be able to read depicted info) - Zoom out (to position information back in context) - Swipe, drag (to find routes and info that are not in screen), tap !!Breakdowns: - Zoom gestures, variable window size, swiping - Unresponsive app: (3 times) close and open again, continue normal operational sequences - Progress through charts by swiping fails → unlearn old way → find and learn new strategy - Handgestures not sensed by iPad or iPad response is incorrect(?) or gesture not executed right way !!

4.3.2 Chart Management After (Unexpected) Software Updates

4.3.2.1 Possible Effects of Software Updates on Breakdowns in Chart Management. One subject matter expert expressed his agitation about a recent software update. Approximately one month before the interview a software update interrupted his regular workstyle and 'comfortable being-in-the-world' (Winograd & Flores, 1986, p. 77,78). It required him to adapt to new handling aspects of the iPad. He used to manage his charts by swiping from one chart to the next while arranging the chart sequence in advance. This required minimal effort and focus for him. However, the software update eliminated the swipe functionality. Now he had to tap in the dynamic aircraft environment by aiming for that small rectangle in the list to activate the correct chart. He found this much harder to do: *'I mean this aiming is harder than swiping left in a very large square [whole screen surface]'* (Figure 12). To illustrate how far the effects of this software update propagated into the system and the pilot's use strategies, this update 'forced' this pilot to have the clipboard in sight to navigate through the chart sequence, which removed the possibility to use the extended chart mode option as described for Figure 12, resulting in less space to depict chart information, requiring him to zoom where he did not have to zoom (as much) before. In itself, these (additional) interactions with the iPad seem harmless, but in a critical flight phase one can imagine this to be some time and effort that one would not want.

A similar breakdown was observed during a discussion on the 'updates' activity card. One of the pilots provided an actual example in which only on the approach procedure[27] he found out that the iPad had been updated. Because of this update, a certain handling strategy no longer worked anymore. The subject matter expert showed on the iPad how he sometimes moved from one chart to the next on the iPad during an approach, in this case from the

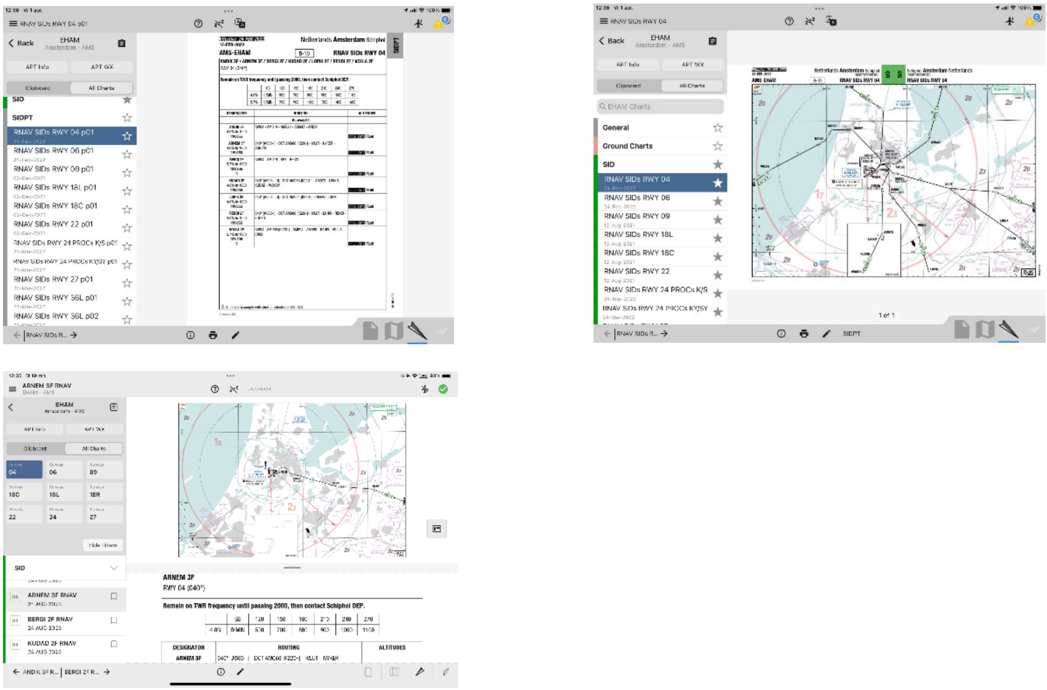
[27] The period in which the aircraft is being manoeuvred to stabilize on the final track and vertical path towards the runway for landing.

approach chart to the ground chart, to create foresight. At least 3 interviewed pilots reported to adhere to this same strategy. After inspecting the ground chart on which he had zoomed in to focus on where to vacate the runway, he wanted to go back to the approach chart. He tried that by swiping, which is what he was used to do and what worked on the previous software version. With the recent software update, however, his swiping did not result in changing charts. The taxi chart remained active, and the information he was looking for just for landing was dragged out of view. He had to drag back the relevant information back into the window and activate the approach chart by applying a different operational sequence than he was used to. These encounters obviously introduced extra (management) efforts. Changing, by software updates, the functionality of hand gestures that formerly allowed pilots to retrieve information in a certain way influenced (as in increased) the amount of time and effort spent on iPad chart management. As will be seen in the following example, such hick-ups do not only result from changes in hand gesture functionalities, but also from updates that change how information is depicted.

Figure 13 shows the extra window sections that appeared on the iPad since the earlier mentioned software update. A similar development occurred for the approach charts. The update thus forced more data (that used to be on two screens) in one screen. Having all departure information in one screen now was perceived as a positive development. However, the new windows also made the depicted information less readable. Every window can be made larger and smaller, but this would come at the cost of the size of the other windows. One interviewee used this strategy to read the otherwise too compact-to-read information. Modifying the window size was observed to be a source of a new way of breakdown though, as one interviewee was observed to accidentally displace the window boundary while trying to zoom in (on the data in the window) and thus had to correct the initial input. Rather than changing the window size, one could also zoom in on the information in the window. One interviewee tried to zoom in twice but both times the ‘zoom input’ failed to zoom in. Another interviewee tried to zoom in five times. It took 8 seconds before the zoom was successful.

Figure 13

Screenshots of departure charts from a previous and updated software version



Note. The upper screenshots show the older software version, where the clipboard presents departures sorted by runway. One page is used to depict the route, the other page shows the waypoints. The lower left screenshot shows the updated version, where the runway is selected in the upper left section, the relevant departure is selected in the lower left section (clipboard), and the routing is depicted in the upper right section, while the lower right section contains the waypoints.

After the mentioned software update, especially the pilot who was still using the old iPad model (the one with the smaller display) found himself zooming in more than before on the approach and departure charts, and on the airfield diagrams. Two pilots called the new way information was presented both a ‘blessing and a curse’. The blessing was that one screen now contains all the relevant information for one specific flight phase, removing thereby the need to manage multiple charts per flight phase. The curse was that the new presentation now required the pilots to zoom in more than before, resulting in the possibility that important information, such as 'warnings' and insets in the charts, may 'fall off the screen'. This of course was not the case with old fashioned paper, charts. The relevance of this particular issue is illustrated by the fact that the theme of 'veiled' information due to zooming in and hence missing other relevant information (e.g. warnings) surfaced 33 times in ASRS, ranking thereby among the highest themes.

4.3.2.2 Wrap up of Findings on Cockpit Ecological Level after un (unexpected) iPad software update. What these examples show is that software updates, a typical feature of digitized artifacts, present themselves unannounced while having the possibility of bringing with them severe consequences for iPad handling. Handling gestures need to be adapted since previous operational sequences no longer work or introduce new breakdowns. Presentation of information altered, that affected the information readability and management thereof. Especially during critical flight phases, this could be a typical ingredient preceding incidents or accidents (see 'going sour', Chapter 4, Para. 4.4), if even it is for a second or two. How this all works, is in many ways new to aviation. Conventionally, cockpits and the artifacts in aviation are more or less built according to standardized principles. With the integration of the iPad in the cockpit, however, standardization is absent because of the software updates that require pilots to adapt over and over again to their artifact, sometimes at moments they don't have the time for it. The iPad relies on the pilot continuously managing the artifact.

4.3.3 Setting the Correct Transition Altitude – Work Changes Throughout Time

Setting transition altitude has to be done in the initial climb out flight profile, which is a critical flight phase that concerns the first minute(s) after take-off. The transition altitude is a clear example of information that has a short but critical operational relevance. *"It's [transition altitude] also critical, you know, imagine if you have to level off pretty low, hey,* *that's just above the transition altitude, yeah then you could be wrong [flying a wrong altitude], it's also important."* There are just a couple of seconds to apply the procedure as prescribed which makes anticipating the moment of applying the procedure crucial[28].

The operating manual dictates that 'the altimeter shall be set to the standard ambient pressure setting when passing the transition altitude' after take-off on an airport. The result of this is that below this altitude aircraft read their altitude by referring to local ambient pressure, while above this altitude aircraft around the world refer to the same standard pressure. The transition altitude varies among airports, which is why pilots are reminded to consult this information every flight again.

The transition altitude is depicted on the right-hand lower corner on a departure chart (Figure 13). However, it was mentioned and observed that, in general, this information is often moved out of sight when handling the iPad, and far too small to read. Shortly before take-off, while on the ground, a lot of things have to be done in the cockpit ecology that leave no space for latter concerns. Because of this, it appeared normal to consult the iPad for the transition altitude only shortly after take-off. Having to search for the transition altitude can result in dangerous situations, because this may interfere with maintaining the correct flight path.

One could argue that it is no problem as one interviewee put it: *"as long as two people [pilots] are sitting here."* With two pilots in the cockpit, one has the role of pilot monitoring. An aspect of the pilot monitoring is to be a source of redundancy, who should 'expeditiously identify prevent and mitigate events that may impact safety margins' or take over when the pilot flying 'is not correcting the flightpath in a timely manner' (Federal Aviation Administration, 2017). This view indicates that the conception of flight operations and pilots

[28] It is common for an aircraft to climb 2500-4000 feet per minute.

implicitly rely on each other's attendance to the cockpit ecology. The sometimes complex interaction with the iPad in the cockpit, however, as this research found out, makes the role of the second pilot especially at low altitudes questionable as a source of redundancy for flying the aircraft. What further complicates the issue is that, as reported by all interviewees, iPad use is not coordinated and simultaneous consultation of the iPad also takes place during flight.

What differs in the digitized cockpit from the paper era, is that historically, the transition altitude was available on a paper chart that did not require as much effort as is now necessary with the iPad to retrieve the correct transition altitude. Moreover, in the digitization process a little, specially printed for that purpose, note block was removed on which pilots used to fill in what they considered essential information for take-off, including the transition altitude. Jutting it down placed the information fresh in the pilots memory and provided a ready at hand and static location of ready to find critical information. With the arrival of the iPad, this notebook was considered dispensable and was thus removed.

The most senior pilot interviewed (starting a pilot career two years before the iPad introduction) flew for a division in which using these notes was not just common practice but '*obligatory*'. Another senior pilot remembered the use of these papers[29] and commented: *'What you no longer do is take notes on a piece of paper and on the basis of the piece of paper brief[30] with sometimes the required charts as addition. Now you sometimes put notes on the [iPad] charts yourself, like these are the altitudes [in case of engine failures] you want to go to.'*

Researcher: "Do you do that too?"

[29] This was during the period that the iPad was already being introduced, over time more paper sources were removed.
[30] *[a prospective discussion on a particular part of the flight with the other crewmember]*

'Yes, I used to do it, but there's an update now that makes the writing less clear [a blurry virtual pen] and therefore less useful. Unreadable. Yes, so such update does influence my flow…'

The pilot referred here first to the change from paper to iPad, after which he started taking notes on the iPad screen. He then discussed that an iPad update now made his notes useless because after the update they were unreadable. Another pilot mentioned to have lost his Apple pen to make notes on (digital) charts, and that he, since then no longer made notes on the iPad.

4.3.4 De-ice Treatment Calculations

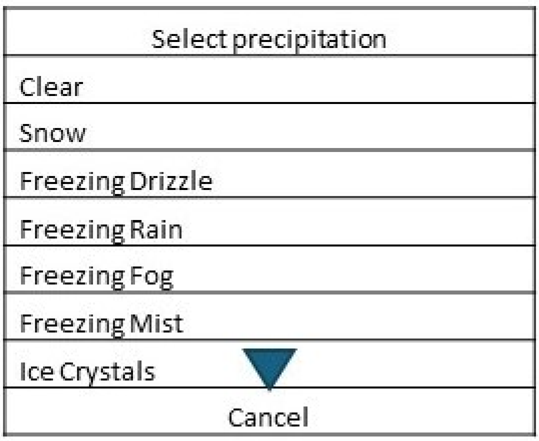
So far, the impact of chart management on the iPad during taxiing has been discussed, as well as the interferences that pilots can experience when looking for the right transition altitude shortly after take-off. The latter especially, because it takes place at a relatively low altitude, illustrates that interferences in activities at the micro level (iPad + pilot) of the JCS, may well affect the wider cockpit ecology, possibly impacting thereby actual flight execution. This was also illustrated by a small experiment on de-ice treatment calculations that was conducted with the informants during the interviews.

What the results of this mini experiment point out, is that even small differences between the iPad and paper documents can have large consequences. The subject matter experts were asked to calculate the correct protection time of a de-ice treatment. In the paper era, pilots had at their disposal for this, a thin booklet containing four dedicated pages with de/anti-ice protection-time tables. All the relevant information was instantly accessible on these pages. The iPad, however, needs to be first fed with the correct ambient information through a drop-down menu and then a scrolling list, before information on the protection times for de-ice treatments can be accessed (Figure 14).

The scenario entailed ice on the wings without any precipitation. Every participant selected in response on this the condition ‘precipitation= clear’ in the drop-down menu. The ‘clear’ label in the iPad, however, represents the ‘precipitation condition’, not the ‘icing condition’ which was ‘active frost’. The difference is that the ‘active frost’ condition has a limit on protection time while ‘clear’ has no limitation, which is a huge difference when applied in active flight, because it can have serious safety implications when the wrong protection time is taken. What this example points out is not that there are bad pilots, but how an apparently innocent change in the depiction of information can lead to a loss in the ability, of not one but many pilots, to select the right flight information, and that such a small change could easily cascade into severe operational failures at macro-level.

Figure 14

A scrolling list shows a list with 7 precipitation types, scrolling down will introduce other types



4.3.5 Charging the iPad – an Emerging Activity

This paragraph focuses on charging the iPad, an activity that surfaced 10 times in the ASRS, making it relatively low in frequence compared to other themes, and that was discussed in interviews after having presented the issue with an activity card. Probing this activity during the interview brought to bear regular breakdowns that affect the cockpit JCS. A reductionist view of the iPad that would exclude the role of that charger and the charging activities would risk missing out important information on the functioning of the cockpit JCS as a whole.

The iPad requires regular maintenance in the sense of charging. All pilots complained about the speed with which the battery of the iPad depletes. This can be annoying because, as we have seen earlier in this research, the iPad must be considered as a cognitive agent in the cockpit JCS. If the iPad fails, the JCS misses out of one of its team players that provides pilots with essential information. Pilots put effort therefor in assuring iPad availability during flight.

Not only does the battery deplete quickly if it is not being charged, the charger (if plugged in) falls out of its socket on a regular basis also. This breakdown in the charging activity was reported by every pilot that was interviewed during this research. It falls out, for example, during a take-off or landing due to vibrations or bumps. The subject matter experts unanimously reported that it either falls out totally (e.g. on the ground or in a crew bag[31] near the pilot), or it is still inserted in the plug (poorly or crooked) but no longer charges. This 'misbehaviour' of the charger causes pilots to reattend to the iPad and its accessories, and to (re-)insert the charger in the socket a second time. The costs of finding and re-inserting the charger are variable, depending on where it ended up after disconnecting from the socket and how well the charger is re-inserted. Finding and re-inserting the charger requires the pilot to look below the iPad or even in a bag, thereby removing sight even further from the cockpit ecology. In practice, the charger can fall out at any altitude. This means that these interferences in activities were reported to also take place below the meaningful altitude of

[31] Crew bags refer to the cockpit crew members' bags, used to carry work related and personal items, they are supposed to be placed beside the seat, which is below the charger.

10.000 feet. Below this altitude the flight is considered to be in a critical phase because of the high workload in the cockpit ecology.

Different charge strategies were identified among the pilots. Half of the pilots interviewed charge continuously from the moment they arrive in the cockpit. One of those pilots reported to deliberately not plug in the charger on one aircraft variant since he knew it would fall out even quicker on that one than on the other variants. It was also found that some pilots charge intuitively, once they see the battery is ‘getting low’.

The formal requirement of having a sterile cockpit during critical flight phases requires loose articles to be stowed. The charger, however, can change by itself from a plugged-in article into a loose article. One of the pilots, who was well aware of the risk that the mentioned breakdowns could negatively affect pilot attendance to the wider cockpit ecology, reduced the chance on these operational distractions by fixating the charger by using a three-pin instead of a two-pin-plug. This meant he reduced distractive activities. This strategy, however, comes at the cost of not following the formal guidelines according to which an official Apple charger must be used.

Quickly depleting the battery and loosing the charging plug from the socket are not the only annoying breakdowns or interferences that the iPad charging system produces as a cognitive agent and team member in the cockpit JCS. It was found during the artifact analysis that charging, according to some ASRS and the informants, also produces a buzzing noise when holding the iPad during that activity. This sound is produced on the headset through which communication occurs between cockpit crew members and between cockpit crew members and air traffic control. The buzzing thus intrudes the cockpit ecological level at which it can disturb important communication.

The researcher and one other pilot also remembered spontaneous and unpredictable iPad behaviour during charging, namely ‘ghost touches’. Both agreed that this could occur at any time. Charts automatically switched in that case, and apps closed down by themselves. These kinds of spontaneous “inputs” from the iPad would trigger pilots to start all kinds of operational sequences to correct the situation and to (re-)manage apps and charts. This phenomenon was, however, not observed in recent operations.

Previously in this thesis, flight phases were pointed out as influencing what activities take place in that flight phase, however, activities not related to that flight phase can take place as well. In this paragraph, the charging-activity with its sub activities was illustratively discussed as an example of this. Charging actually is a maintenance activity that can emerge and interfere in any phase of flight, at times temporarily removing the pilot almost from the wider cockpit ecology. Because of its normalcy, it is almost easy to forget that the activities related to charging the iPad should be regarded not as normal but as additional pilot duties that were not present in the paper era. These additional activities were only but inevitably introduced with the digitized and plug-in nature of the iPad in the cockpit.

In table 5, the charging activity has been presented in the human-artifact model. It includes the tensions and breakdowns in the JCS as a result from the charging activities The red exclamation marks show what tensions and breakdowns are experienced. The lightning strike symbol is placed between levels or between the artifact and human column to indicate where tensions were found.

Table 5

Human artifact model with activities surrounding charging of an iPad in relation to the cockpit ecology activities

Cockpit ecology	Human
Controlled flight	Control flight
Represent aircraft status Control aircraft Communicate with traffic control and colleague	!! View and hand removed from cockpit representations and controls!! -!! Interfering buzzing noise on headset!!
Show speed/ altitude/attitude/ aircraft location/ charts Facilitate steering Pass through audio from air traffic control and colleague on headset	!!Pick/ find charger up after fallen !! !!(Re-)insert!!

iPad battery (Activity: charging)	Human
Allow iPad to be on	Have iPad on any time during work with correct info
Supply electric energy by battery - !Sudden random behaviour, e.g. closing apps, switching charts!	Having iPad on !Buzzing sound on headset while holding and charging iPad! - !Ghost touches!
Charging of battery with charger - !Only apple charger allowed! - Never charge during lightning - Charged sufficiently before flight	- Charge battery by having charger plugged in - !Charger falling out or half out of plug! - !Use of non-Apple charger (that doesn't fall out). ! - !Weak charger! - !Weak battery, hard to charge quicker than discharge!

4.3.5 System Propagation and Complexity

What paragraphs 4.3.2 and 4.3.3 point out is that the implementation of the iPad does not simply replace the old paperwork, it changes how the whole cockpit JCS works. Paragraph 4.3.4 in turn, points out how the iPad introduced additional activities into the cockpit JCS. The iPad introduces new functionalities that require new skills (e.g. new handgestures) to use it fluently and prevent breakdowns, and it erodes old work patterns.

In the paper era, each pilot had (two) maps at hand, one for each airport that was visited. The appropriate charts were arranged in a logical sequence and collected from the map when necessary. Also, a special note block was present, developed to jot down departure information. All relevant information was statically depicted on a piece of paper and once the paper chart was found and placed on the clipboard, no further managing was necessary. The iPad, on the other hand, requires a considerable amount of interaction, because the relevant information can be constantly moved, on (and off) the screen, by zooming in and dragging information, while encountering breakdowns and operational glitches. At times important information, instead of being directly presented on a page, can only be acquired after scrolling through a drop-down menu or document. These aspects of the iPad introduce serious new risks, especially at lower altitudes (below 10.000 ft) and on the ground.

The note block was removed from the cockpit once the iPad was introduced. Some pilots then started taking notes on the iPad screen. One downside of this, however, is that active (handwritten) note taking works better in memorizing them. The digitizing of the environment eroded this. One pilot, moreover, said he stopped making notes at all once he lost his stylus pen, which is much harder to replace than a simple ballpen. The iPad, moreover, is updated regularly, and a recent update has made taking notes useless because they are, since the update, unreadable.

In addition to the issues mentioned in this paragraph, remember that the first phase of this study started with reading ASRs. IPad handling and information representation were mentioned in these ASRs regularly in relation to occurrences such as runway incursions, altitude deviations, abnormal aircraft attitudes while hand-flying (up to a 60-degree bank angle) and ‘terrain – pull up warnings’. These are all clear manifestations of how the implementation of the iPad at the micro level can propagate in complex ways into severe deviations at the wider cockpit ecological level.

4.4 The Real Work – Working With and Around the iPad

The informants reported that, although subject to individual differences, factors that lower the cognitive demand of pilots, such as being familiar with an airfield, reduce the consultation and use of the iPad charts. One pilot even admitted to never have his chart app opened at the homebase to focus on what happens outside. This, however, is a non-compliance with formal use requirements.

The informants reported more of these kinds of attempts to control the messiness they think the iPad introduces in the cockpit. They mentioned, for example, that they preferred not to use the iPad during taxiing in real work conditions. At the same time though, they also reported that it was common for them to consult the iPad during this phase, which indicates that iPad use occurs beyond what is conceived as desirable by a pilot.

One important finding was in fact that certain (aspects of) flight phases, would more or less dictate the use of the iPad and also, sometimes, how it is used. When airport details and regulations are considered relevant, for instance, the pilot has to consult the iPad, while the type of information needed also influences what app (or functionality thereof) is consulted and what data is retrieved. Half of the interviewed pilots have experienced consultation of the iPad at the same time as their colleague did, especially in cognitive demanding situations such as the receipt of a clearance, especially when the clearance deviates from what was expected. The consultation of the iPad agent in the JCS, and sometimes even how it should be consulted, apparently is directed by certain (aspects of) flight phases that dictate specific cognitive requirements.

According to the informants, there is no limit to the iPad use. In practice, it can be used at any time. Indeed, iPad use at (very) low altitudes, both by the pilot flying and the pilot monitoring, as well as during departure and on approach, was reported to be normal by all subject matters experts.. *"I never put it away, not even in critical situations or anything ... right after take-off I might read a SID [departure route] to find out what the transition altitude was again ... While it's actually a very critical moment."* All pilots reported to experience the consultation of the iPad as something crewmembers perform simultaneously with other tasks in the JCS. What this indicates, is that the iPad can be a source of messiness in cockpit work.

4.4.1 Trial by Error as a Primary Means to Learn to Work the System

Besides the communication of a few formal use-constraints that according to the informants in practice have little effect, all subject matter experts made it clear that there is no training in iPad-use. The iPad activities in practice therefore remain fairly uncontrolled and are generally left to the individual pilot's practical task integration. The constellation of possible iPad use configurations, moreover, are not pre-defined, let alone prescribed and practiced in training. Since there is no training, these (new) handling aspects of the iPad are generally learned through 'inference' (D. Woods et al., 2010, p. 106) and 'trial and error' (Raeithel & Velichkovsky, 1996, p. 202). This introduces a dilemma. Raeithel and Velichkovsky (1996) point out that 'the more you design for freely choosable, trustworthy possibilities for users, the less you will be able to foresee the possible breakdowns of expectations that users may experience with your new design features'. This would imply, and so it was found during the interviews, there is no certainty about the way in which pilots start to use the iPad, and accordingly what breakdowns (in expectation) each of them encounters during its use.

The lack of formal training on the iPad may exist because it is difficult to realize because of the recursive updates an iPad can have due to its digitized fluidity. Anyways, the informants reported that the way a pilot works with the iPad is left to the individual pilot. This research indeed found variability between individual pilots regarding iPad use strategies. Variability was found, for instance, in *what* is used on the iPad (e.g. different apps), as well as in *when* the iPad is used. Consulting the iPad, on the other hand, is not totally random. It is more that individual learning takes place. As one pilot mentioned, "*I think gradually my usage has streamlined, because you know much better what you want and when you want it*".[32] In general, one could better speak of pilots having a preferred style of use, more than of formally communicated use-boundaries. The variability found though, confirms that the iPad can be a source of messiness in cockpit work.

4.4.2 Going Sour a Little Bit, Time and Time Again

Going sour, a term that was introduced by Woods and Sarter (2000, p. 331), refers to 'breakdowns in coordination between crew and automation' that creates 'the potential for a particular kind of accident sequence'. The data from the informants suggests that pilots working with the iPad are confronted many times with mini (coordination) breakdowns due to, for example, iPad updates or glitches.

4.4.3 The iPad: an Intuitive but at Times Unthrustworthy Partner?

The iPad is typically controlled by a range of hand gestures. The difference between swiping with two, three or four fingers can give a totally different outcome on the screen.

[32] It became clear at the same time that norms such as, 'better knowing what you want', do not crystalize in some absolute way.

During the interviews, it became clear that both the hand gestures used, as well as the awareness of which hand gestures could be applied, varies per person.

Operating the iPad normally takes place, according to the informants, in a more or less routinized manner. This routinized practice was observed during the interviews. As subject matter experts retrieved charts, they barely mentioned the operational sequences they had to perform to retrieve a chart and its information. The following example is illustrative of how the manipulation of the iPad is not mentioned. On final approach (a minute before landing) the pilot wants to increase awareness of the appropriate runway exit. The pilot explains how he checks himself of taking the correct exit.

Pilot: "Yes, yes, and then I would just ...like thiissss [he grabs the ground chart], you know? Yeah, oh, I want to take Bravo [a runway exit] and then I'll just go. Like this [he moves his view from the iPad to the view outside], ah yes... That's say, yes Bravo, oh that's the second hi speed exit, look that's the one so there.

Researcher: "So, you just went from approach to ground chart, [you] zoom in for a moment, then zoom out again… "

The pilot did not mention the handling aspects of retrieving charts and zooming in and out.

The iPad interpretation of a hand gesture can also change, such as with a software update, or when the iPad is not responding as it should for unknown reasons. One pilot, for instance, suddenly experienced resistance in working with the iPad after an update in which the swipe-option to move from one chart to the next was removed. While his goal and thus the action (switching from one to another chart) remained the same, the conditions (in the iPad) had changed. Consequently, the operational content of his action had to change (Leont'ev, 1978, p. 47). This is where the pilot had to change from unconscious to conscious handling on the operational level. Not only did he have to adapt and learn to use the iPad again in this particular situation, the new handling aspects and the interference also cost pilots' cognition and time. The consequences of these interferences were also experienced during critical flight phases. The experienced resistance of the iPad in work, the breakdown in coordination between pilot and iPad, was repeatedly mentioned during the interview by the pilot: *'it doesn't cooperate with what I want to do'*. Another pilot commented about an updated flight plan app: "*you have to learn first, eehh, and then you can already see a bit of what is different about it than the previous one. Some things are in a different place. it's actually nicer but still you have to get used to it"*.

4.4.4 The iPad: a Source for Messiness

What can be realized from the paragraphs above is that adhering to work-as-prescribed (a 'sterile' cockpit and low workload during critical flight phases, no distractions, etcetera) is unrealistic in practice because the interactions with the iPad rather increase during phases of high workload, and its use has been experienced as interfering with other tasks. The reason for prescribing minimal iPad use during high workload is understandable but impractical.

A focus on the iPad's digitized fluidity and multiplicity, as has been done in this research, has not only shown the 'iPad-component' to be a source for breakdowns in cockpit activities, but also as a resource for resistance to standardization. This, in turn, impedes the setup of formal and recurrent timely training, because of which pilots learn to use it by inference and the development of individual habits, preferences and strategies. Pilots, in other words, adapt as the interplay between components evolves. Consequently, the local interplay between components gives rise to emergent and messy activities that challenge the notion of standardization in flight operations.

5 Discussion

I have tried to gain an insight in this research in how the iPad functions as a cognitive agent and a team player in the cockpit JCS, and how it has introduced with its digitized features, a certain amount of complexity in this eco system, a certain amount of complexity that used not to be there in the paper era. The pilots, for instance, have to train themselves in the use of the iPad (like how in everyday life we are used to do this nowadays with our many handheld digital devices), because the update frequency of our devices would render any training for these devices obsolete with the blink of our eye. The result of this self-education is that activity initiation and coordination depend on the style of the individual pilot, and on the situation at hand. This made activity analysis more meaningful than a task analysis.

This study, by methodology, the activity analysis and JCS as a basis, was set up to move away from some idealised iPad and Pilot paradigm, i.e. an idealised framework of understanding flight operations with the iPad as something quite similar to that with paper. Rather than studying work-as-prescribed, this study aimed to study the actual work of the pilots with the iPad in relation to their cockpit ecology. It studied, in short, how the iPad introduces complexity and messiness where this used to be absent, and how it does this. To this end, I studied in what ways iPad related activities with its digitizing aspects interact with other coordinative tasks of cockpit crewmembers during flight and how this would influence flights. I started with a focus on the features of the iPad, then on the activities of the pilots and the iPad, to shift at the end towards how this influenced the cockpit ecology, the whole cockpit JCS and resulting flights. I thus moved from inside outward, relating in and out to each other. To a certain amount I have also moved from history (the paper era) to the present, trying to interpret changes between these timeframes in terms of complexity and messiness, in an aim to bridge the gap between work-as-prescribed or some ideal notion and actual work.

The results have shown changes in the nature of work in the cockpit JCS related to the introduction of the iPad. The iPad can be said to have altered many activities when compared to the paper era, and to have introduced new activities. It has altered work patterns, and some of these changes actually tend to affect the performance of the cockpit JCS (cockpit ecology) during critical flight phases. Signs thereof I was able to present in this research, found especially during taxiing, which is a critical flight phase that is still relatively permissive, but also when applying the transition altitude after take-off, de-icing and charging. The ASRSs, however, suggest that iPad handling interferes with many activities of pilots, during even far more critical flight phases.

5.1 Joint and Distributed Activity

According to Klein et al., ‘performance depends on coordination as cognitive work is distributed among different team members’ (2005, p. 3). Today, these team members often include artifacts. Pilots, for instance, ground their actions in knowledge about the system they operate in, which includes the iPad these days. Pilots today are supposed to look up information on their iPads during flight, to study this information, and to apply it if considered relevant for the flight. For that reason, I conceptualised the iPad as a cognitive artifact that requires ‘bodies of action with a beginning and end’ (Klein et al., 2005, p. 32). The interactions described by the informants in the interviews gave away how operational variables affect each other. The iPad appeared to introduce many of these kinds of variables, e.g. the ‘battery low’ or ‘not charging’ indication can start up the ‘charging’ activity, or familiarity with the airport may reduce iPad interactions, etc. Not just the pilots, but also the iPads were found in this study to be flexible agents, hard to define as components that solely work in a linear and mechanized way.

The artifact analysis taught me as a researcher about the adaptive and transformative aspects of the iPad. Investigating what the iPad 'is', what its features are, how the digitized aspects of it work, where it is situated in the cockpit, what the formal guidelines for use are, etc., further helped me to enter interviews and probe about a broad range of aspects and thereby acquire data that extends beyond the native view what pilots would discuss by convention. The interactions described by the informants during the interviews then gave away how activities with the iPad are being performed, and how work in this context gets distributed between the pilot and iPad agents from the pilot's perspective. Besides the usual finger trouble and related breakdowns that may occur in the iPad-pilot interaction, which happens in the interaction with any digitized device, the iPad may suddenly alter 'by itself'[33], due to glitches or some software update for instance, after which information may unexpectedly have moved to another place, or out of sight in a configuration. In chapter 2 I referred to this as digitized fluidity. The iPad could also have stopped charging all of a sudden, consequently requiring attention to re-start charging, or stop working altogether. These kinds of issues, this research points out, may well propagate into breakdowns in the cockpit ecology activity, and thus in-flight performance, because this may hamper the retrieval of relevant information on unexpected and critical moments, or result in wrong flight related data.

The insights provided confirmed performing a study away from an 'idealized component' paradigm only made sense. From a JCS perspective, the iPad was studied as an agent that performs actions in the cockpit ecology over time, that changes behaviour, handling aspects and content, of the system as a whole, and of the pilots within that. As mentioned in chapter 2, this study did not focus on agents beyond the cockpit ecological level, e.g. those

[33] What is meant with 'by itself' is: without any action required from the pilots or the airline.

responsible for updates on the iPad were not integrated in understanding the iPad and its ecology.

5.1.1 Common Ground

'Common ground', as discussed by Klein et al. (2005) and in chapter 2 of this research, is one of the three requirements to engage into joint activity. The other two are directability and interpredictability. In this paragraph, I will focus on 'Common ground', the other two concepts are discussed in depth in the next paragraph. 'Common ground' refers to a set of shared knowledge, beliefs and assumptions[34] among (and internal to) agents, which allows these agents to jointly perform activities. I chose to use this concept in my discussion since the iPad is a cognitive artifact, and an agent that has to (jointly) perform flight related activities. Common ground can be used to discuss breakdowns at the cognitive levels.

In dynamic systems, it is inevitable that common ground varies in quality. However, harmful qualitative discrepancies should be observed and dealt with on time in order to operate safely (Klein et al., 2005, p. 11). Zigzagging during taxi due to iPad interaction for example, can be seen as a reduction in common ground quality because the pilot taxiing (unwittingly) deviates from the taxi-line while checking the iPad, while the pilot monitoring (as part of the cockpit ecology) probably sees the deviation but does not know to what extent the pilot taxiing is aware of it, nor when a correction will be made. Between the pilot and the iPad, the only of these two agents that can catch any serious discrepancy is the pilot, since the iPad, as it is now at least[35], is not capable of sensing these kinds of disturbances. Not catching a serious discrepancy in any joint cognitive system could develop in a Fundamental Common

[34] It includes 1) knowledge of roles, functions, standard routines; 2) mechanisms to prepare, monitor, sustain, catch and repair breakdowns; 3) commitment from both parties to keep working together and adjust common ground (Klein et al., 2005, p. 37)
[35] AI may change this capability over time

Ground Breakdown (Klein et al., 2005, p. 19), which is a breakdown process that evolves into a coordination surprise, often associated with serious loss of common ground. In such a case, (critical) cognition is no longer distributed effectively among agents and a coordination surprise may occur, implying that – quite similar to breakdowns (Winograd, 1986) – an agent is surprised by the way another agent acts in the JCS. Distribution of cognition is thus impaired in the cockpit JCS due to iPad interaction. In chapter 4 we have seen that discrepancies at the micro level may propagate into disturbances at the cockpit ecology level. Of course, a surprise that has propagated up until the cockpit ecological level is considered much more serious than a discrepancy that stays at the pilot+iPad level[36].

During flight operations, the iPad does not (actively) share in knowledge, beliefs and assumptions of the pilot and aircraft in the situations at hand, neither can it experience a coordination surprise. Therefore, the artifact lacks the quality of a real team player during flight operations.

5.1.2 Interpredictability and Directability

Besides the concept of common ground, Klein et al. (2005, p. 9) presented interpredictability and directability as two other prerequisites for establishing joint activity between agents. Interpredictability refers to 'the ability to predict the actions of other parties [in a joint activity] with a reasonable degree of accuracy' and is necessary to maintain common ground (pp. 2, 9). Directability refers to 'deliberate attempts to modify the actions of the other partners [in a joint activity] as conditions and priorities change' (p. 12). Inadequate

[36] Actually, while writing the discussion, a pilot from another organization with a similar operational landscape as my own organization (Pilot from other organisation, personal communication, April 5th 2023) shared that one of their flights ended up 'in the grass' during taxi, and another clipped an aircraft with its wing during a tight turn on the ground. Both happened while the iPad was being consulted. These occurrences are signs that transferability of this research is achievable.

directability affects predictability in a negative sense and that in turn decreases interpredictability, which is typical for how breakdowns develop. That is why these requirements are treated together in this paragraph.

As was discussed previously in this thesis, the pilots' attendance to the cockpit ecological state is supposed, according to formal documentation, to be maximal below 10.000 feet. Below 10.000 feet, in other words, pilots are supposed to have all their attention directed towards flying the aircraft and all that belongs to that, and nothing else. In my organisation, for instance, it is formally trained and instructed as pilot flying to not even type below 10.000 feet on a fairly simple screen. This is to assure a maximized directability by the pilots in relation to achieving and maintaining common ground (and thus interpredictability) with all the cognitive agents in the cockpit JCS. This research, however, found ample activities taking place on the iPad below this altitude, also by the pilot flying. Often this was the result of a double bind for the pilots, such as that they need the implement the transition altitude shortly after take-off while note blocks to note down this altitude (and help memorize that altitude) have been removed from the cockpit with the iPad, which points out an operational contradiction. The interviewees also reported that air traffic control clearances may trigger the two pilots simultaneously 'heads-down' by placing their attention on the iPad's and/or FMS. Without coordination this temporarily isolates the cockpit ecology from the only agents that are able to prevent coordination surprises.

5.1.2.1 Directability (and thus Interpredictability) in Actual Conditions. In this research, the iPad has been presented as one of the cognitive agents in the cockpit JCS. This is because, as this research points out, the iPad mediates and sometimes even modifies the pilots' actions during flight since handling the iPad often requires a range of activities, and may even require the pilot to perform new activities in flight unexpectedly, when information fell 'of screen' or after a software update for instance (which may require a significant amount of cognitive effort to find out what activities are needed). To effectively maintain common ground between agents in a joint activity, Klein et al. (2005, p. 36) state that 'agents must be able to actively seek to conform to the needs of the operators, rather than requiring operators to adapt to them… agents have to become more understandable and predictable, and more sensitive to the needs and knowledge of people.' During flight operations, the iPad does not actively seek to conform to operators, and it lacks sensitivity to operator needs. The iPad also cannot be regarded to act deliberately, because the mediations, such as information that was (re)moved, spontaneous glitches, or the need to recharge the iPad, occur non-deliberately and are not related to specific operational conditions and priorities. They simply emerge from the presence and update status of the iPad. Pilots, in contrast to the iPads, are deliberate initiators and modifiers and are sensitive to any failings of e.g. the iPad's functioning in the team. Pilots deliberately perform actions on the iPad and deliberately make sure that these actions concur with the current conditions and priorities. Directability thus lies by and large with the pilots. At the same time, however, the digitized aspects of the iPad, the digitized fluidity especially, may hamper the pilots' ability to direct, which may go at the cost of breakdowns at the cockpit ecological level.

This research nevertheless did not find hard boundaries laid upon iPad use in flight with the organisation studied. The operational manuals, moreover, mainly depict work as prescribed, the ideal typical way of working with the iPad, under-representing thereby guidelines on how to cope with actual flight conditions, such as double binds. What common ground with the iPad is supposed to look like remains unclear also. What this study and paragraph bring to the surface is that the formal documentation in fact implicitly relies on the pilots' ability to direct the iPad's fluidity with its ill-defined and constrained 'bodies of action' as a requirement for the successful achievement of joint activity between pilot and iPad in the cockpit ecology, and that it thus resorts to problematic concepts, e.g. ‘avoid distraction’, ‘fixation’ or ‘minimal’ and ‘normally’ (see 4.2.3), for the establishment of safety.

Pointing this out is all the more important because breakdowns in aviation are usually prevented or mitigated in many ways. Logbooks, for instance, are kept on the technical status of the aircraft. Aircraft can be kept grounded. Checklists are to be consulted in the air to assure an effective reaction on abnormal aircraft behaviour. Pilot training, moreover, is given on a regular basis to effectively integrate the pilot in the aircraft. All these measures help to maintain a common ground between agents that permits successful flight performance. However, all these kinds of tools do not exist for the iPad due to its digitized fluidity. Moreover, as mentioned earlier, there exists no coordination between the pilots on their iPad use, because of which the second pilot can not be considered an effective source of redundancy. At the same time, indications were given in this research (see 4.3.2) that pilots implicitly nevertheless tend to rely on the presence and capacity of their colleague to intervene on developing coordination surprises, on deteriorating situations of the flightpath or aircraft trajectory[37].

5.2 Uncovering the Untold through Methodology: Re-conceptualising the iPad as Unruly

Wynne (1988) discussed unruly technology by three aspects: practical rules, impractical discourses, and public understanding. By “unruly” he refers to technology in a social context, where it is often shaped by organizations and individuals in ways that were not foreseen when it was first developed. As a consequence of this embeddedness in social practice, new rules and phenomena emerge from this practice, rather than that rules

[37] Both pilots can steer the aircraft in the air, on the ground steering can be done from the left seat only.

necessarily control practice. Reconceptualising the iPad as unruly technology according to Wynne's framework, I believe, provided me with a richer, more realistic understanding of the iPad within the organization.

Two aspects of the methodology, I believe, have especially helped me in this research, to capture the unruliness of the iPad: the use of more than one unit of analysis, and the observation of actual iPad handling.

The two units of analysis used in this thesis (micro and cockpit ecology level) allowed me to switch perspectives during the interviews, and to learn more about the relationship between these two levels. If flights as a whole were used as the unit of analysis, the micro activities that create success (or failure) during flight are easily overlooked. Zooming out and asking for scenario's where the aircraft trajectory was considered compromised because of iPad interactions (see 4.5.1) produced much less accounts of breakdowns then those that focussed on the iPad only. This is because not each breakdown eventually results in a reduced flight performance. After all, many breakdowns at the micro-level are solved at the micro-level. Starting an analysis at the cockpit ecological level therefore would have left out a lot of activities, and thus performance efforts, that take place at the micro level that could interfere with the cockpit JCS in a negative way. Focus on activities at the micro level in this thesis, connected to insights on the cockpit ecology level, increased the observability of breakdowns at the micro level within the cockpit JCS as a whole.

The application of activity theory – by using the method of observations especially - allowed me to become aware that learned handling in activities with the iPad leads to unconscious, routine-like actions that are typically not verbalized. As it was pointed out during this research more than once, the iPad needs to be adapted to by the pilots in the cockpit ecology each time it is updated. Once this adaptation has been turned into learned behaviour, however, the amount of effort that is needed for this adaptation - the activities and cognitive efforts that the iPad adds to the cockpit ecology - often disappears from the general discourse on the iPad. The process of normalization of activity, in short, often disappears from the discourse about the iPad. It is needless to say that this contributes to an impractical discourse on the use of the iPad that often fails to capture the nuances of actual work. The added activity, however, could still be captured by critical observations, as was done in this research.

Developing appropriate units of analysis and switching between them, as well as the addition of observations of actual iPad use during the interviews to maintain sensitivity to not just verbal but also non-verbal expressions of activity have proven invaluable for understanding the dynamics (activities) within the cockpit JCS in a rich way. Without the addition of the observations these were likely to have gotten lost in the general discourse and public understanding. This approach not only enriched the findings and the interpretation thereof, but also demonstrated the necessity methodological strategies in complex systems studies.

5.3 Reflexive Practice on Models.

The reflexive practice of writing my thesis brought me to the following insight on the use of models. This study has shown a vast range of possible (regular and irregular) activities that can take place during flight operations, that consists of yet more activities. It has also shown how activities can have different operational sequences.

The strength of the human-artifact model, is that it has been an outstanding tool to be confronted with the many activities that take place, and with the fact that the iPad and pilot are dynamic and flexible agents. by including the micro and the cockpit ecological level as units of analysis, it allowed, moreover, a visualization of not just breakdowns at specific activity levels and between different agents, but also of tensions between these activity levels.

5.3 Proposals for Future Research.

Besides proposing a new way to study artifact related activities in a larger work system, this research draws attention to the multiplicity of possible activities on which further research can be performed. To understand the (developing) landscape of (possible) breakdowns due to the iPad introduction, research is advisable of both conscious and unconscious activities before and after updates. This facilitates organisations to whom it is relevant to observe and understand better (emerging) breakdowns, and to deal with them a priori, e.g. by training.

A more holistic activity theoretical approach on studying activities in relation to artifacts could be helpful also. A useful framework for this is Engestrom's (2000), who understands activities as a collective undertaking in a larger framework of activity stakeholders. These stakeholders would be located beyond the cockpit JCS (yet are acting upon the cockpit ecology through the iPad such as those who update the iPad). Keeping in mind what was mentioned in chapter 2 (para. 1), that the use of an artifact is shaped in a "web" that belongs to a certain community of practice, this framework would include broader than presented in this thesis rules, division of labour, and the community as components that shape activity (Figure 15). This approach would allow activities to be understood, not as isolated activity in the cockpit, but as activity related to these components. This approach would further allow to develop shared ownership over activity introduction and transformation. This research has already started a move towards this approach by touching upon (the lack of) rules and influence of software updates (developed by the community) on activities.

Finally, a stronger focus in future research, on the cockpit ecological level during iPad activities and ‘the other pilot’ in the cockpit ecological level, would complement the results of this research in that this would help identify how pilots prevent breakdowns at the micro level to propagate up to the cockpit ecology level.

6 Conclusions

‘Products and prototypes embody hypotheses about what would be useful’ in performing work with these products and prototypes (Woods, 1998, p. 170). The iPad is seen as a useful tool for flight operations, also when asking the pilots about their general opinion. This research nevertheless found that this artifact introduced new and altered activities to the work as an airline pilot when compared to the paper era. How these revised work activities relate with the larger work system was consequently investigated (Woods & Hollnagel, 2006, p. 50). The results allow a greater understanding of the 21stcentury digitized cockpit in which new, off-the-shelf, bring your own, plug-in, and minimal-standardized - forms of information technology are managed. The understanding of how this artifact changes the cockpit ecology both at the micro, the meso and the macro level matters not only for the pilots at the sharp end studied here, but for all who are in some manner involved with the iPad implementation, including, for instance, the European aviation organization EASA, since, as the ASRs studied in this research pointed out that multiple EASA safety goals (EASA, 2019)[38] were affected due to iPad related incidents.

The research question that stood central in the research was:

- In what ways do iPad related activities with its inherent digitized aspects interact with other coordinative tasks of cockpit crewmembers during flight and how does it influence flights?

[38] There are five EASA safety goals, the ASRS relate to three goals: runway incursions, controlled flight into terrain and loss of control in flight.

What this research points out is that the iPad is an artifact that has become embedded, once it was introduced, in social and individual practice. As a consequence, rather than rules controlling practice, phenomena to be observed in relation to the iPad appear to emerge from practice and local behaviour. Because of the iPad's fluidity and individualized use, the artifact introduces in the JCS some operational ambiguity that is difficult to determine by some overall rationality (Wynne, 1988). Especially because of its regular and unannounced updates, the iPad produces an ever changing constellation of new configurations and newly mediated activities to which each pilot individually responds. In a context of little to no formal guidelines, pilots tend to develop their own way of initiating and handling the operations associated to these activities. Discussing those activities especially, it became clear that interferences often present themselves during phases of high workload that often require added intense cognitive work. The iPad thus becomes part of, but also adds to, the pilots' workload. It is no wonder that the pilots report that these interferences and revised activities can develop into breakdowns, that often remain confined to the micro-level, such as when a chart has to be dragged to different corners to present the relevant information on the screen, but that have, at times, the potential to propagate into the cockpit ecological level, with a severe risk for flight safety.

What is remarkable when considering the findings of this study, is the difference between the organizational communication about using the standardized and built in aviation equipment (such as the flight management system (FMS), which is a fixed little computer screen in the cockpit), and the iPad. The FMS is explicitly warned for as a possible source that may introduce competing activities in the cockpit (*FMS Data Input Errors | SKYbrary Aviation Safety*, n.d.). My organization took measures to coordinate the FMS use below 10.000 feet, and this is kept in mind during training and respected during actual flight operations. The performance to operate and direct the iPad comes for the majority as this thesis shows, from the pilots' efforts. The iPad obviously has the ability to affect the pilots' attendance to the cockpit ecology, but training is not received by the pilots, and operational documentation covers the iPad poorly [39].

This research did not provide some bite-sized chunk findings in the form of a generalized narrative or quantitative proof that would prioritize what to give attention in relation to iPad use in the cockpit. It rather described and analysed the iPad related and messy activities that emerge during flight operations. It can therefore enrich the general understanding on actual flight operations with the iPad. It may make airline managers, including pilots, more aware of the fluidity of the iPad, of its use during flight operations, and of what kinds of consequences this may have, not just for iPad handling, but also for flight safety.

Last but not least, I hope to have contributed to a research topic that is very actual though left poorly discussed. And to a methodology that will spur further research on ways in which work transforms and often keeps transforming under the influence of digitized artifacts.

[39] From the 'common ground' and activity theoretical perspective.

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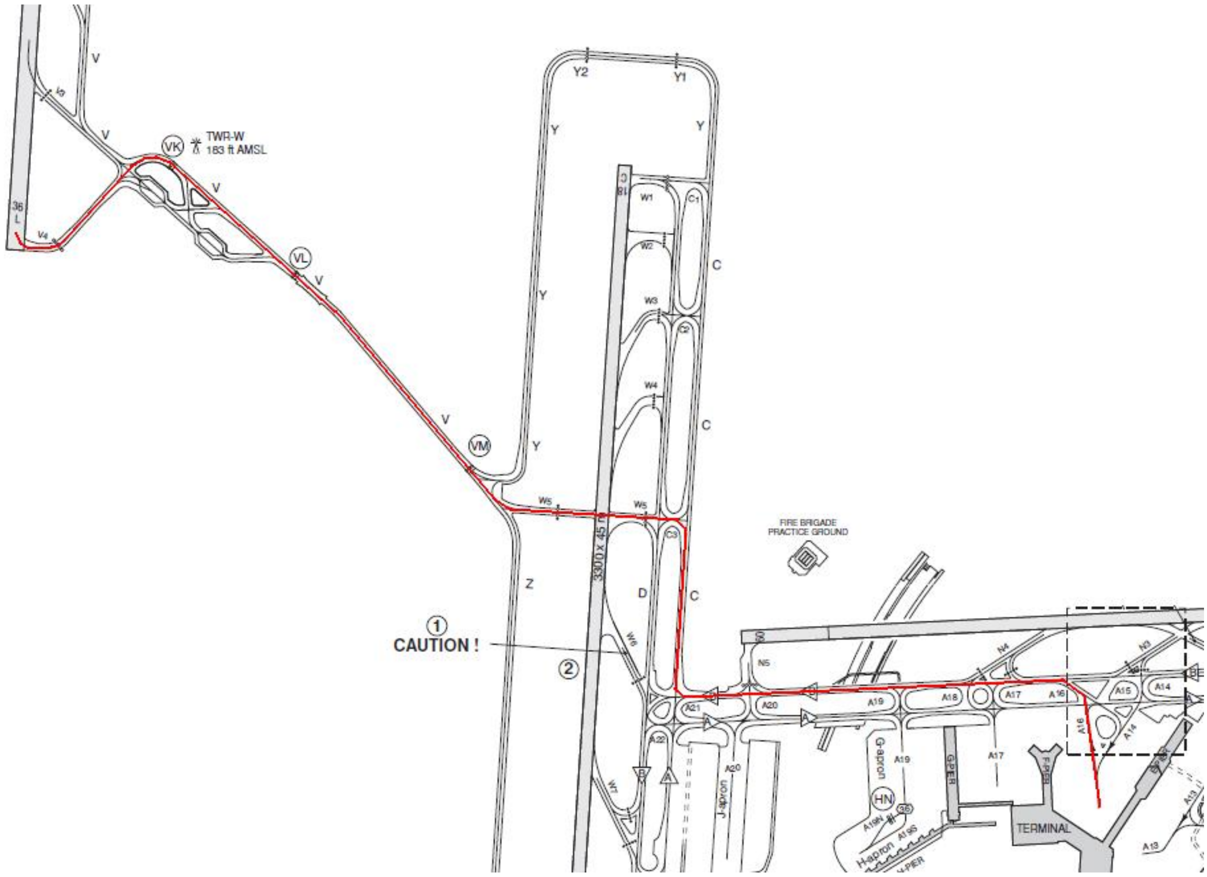
Appendices

Appendix A: Flight Profiles



Note: Profile to discuss pushback, taxi-out and takeoff roll

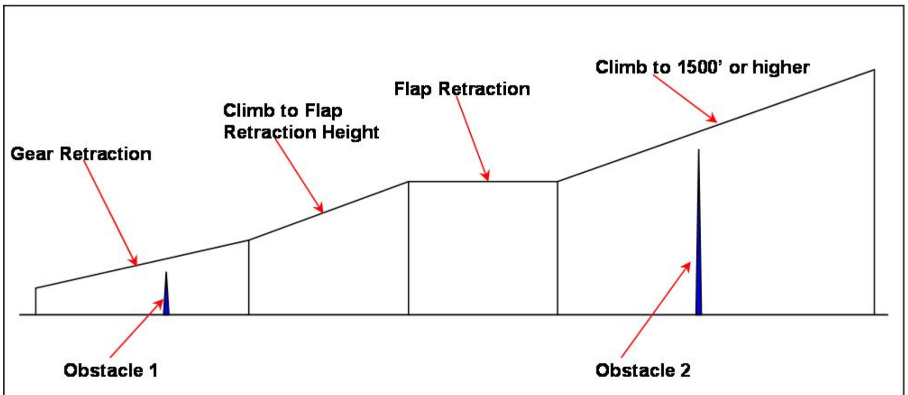
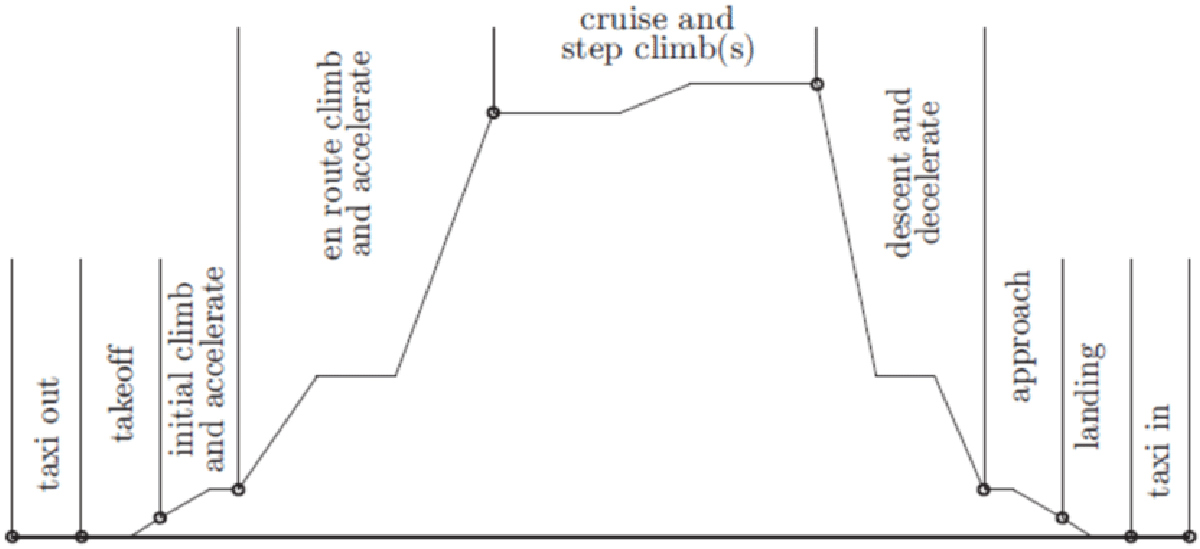
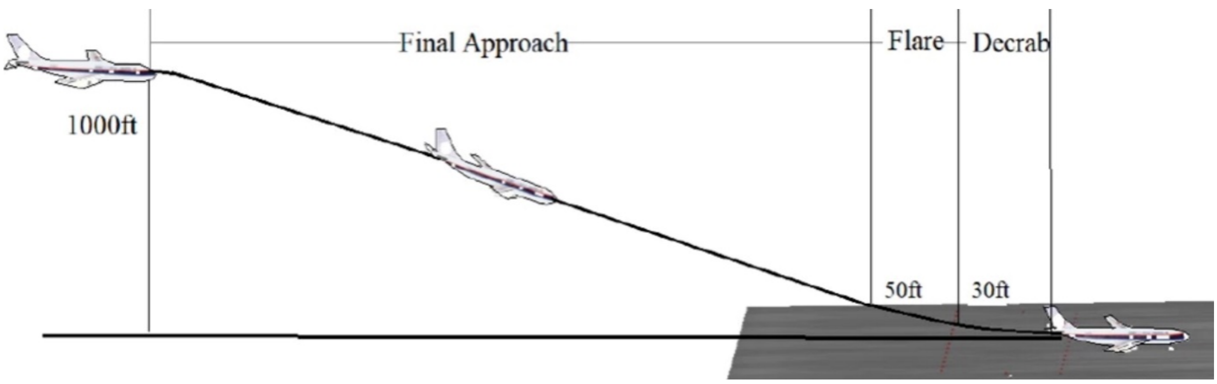


FIGURE 1—TYPICAL NET TAKE-OFF FLIGHT PATH

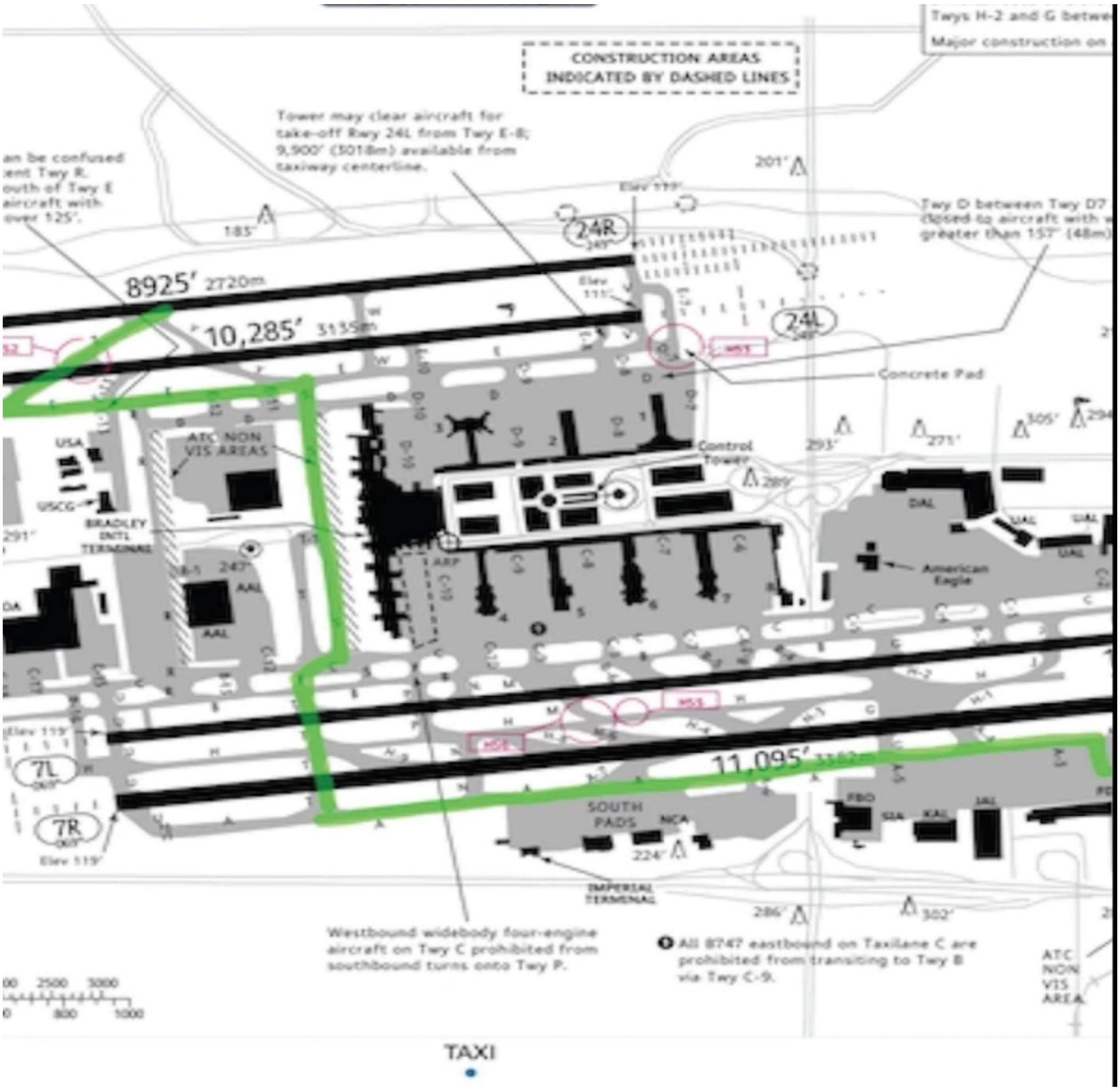
Note: Initial climb-out phase



Note: Flight profile to discuss important altitudes like 10.000 ft, step climbs, descents etc.



Note: Profile to discuss final approach, flare and landing rollout



Note: Profile to discuss taxi-in, vacate runway and parking phase

Appendix B: Activity Cards

Charging	Find ground chart	App Management

Note: Example of activity cards

Appendix C: List of Questions with Interview Protocol for Artifact Analysis

Semi structured interview for artifact analysis (probe during the answers about why/what/how):

1) Let's have a look at the iPad hardware/software variables introduced by iPad developers and management.
   A) Can you point out what we deal with (on board)? (**Make activity cards** from these answers)
   B) How was this before the iPad?

   - By focusing on the iPad, I avoid general discussions about work and focus on what sort of activity is introduced by the artifact. It relates to sensing the image of work through the iPad and tells about iPad activity possibilities. Both for the way it was 'designed' and a little about which is used.
   - This question will be used to make activity cards.

2) How did you deal with what we have found in question 1 through the iPad **(explicate with examples, illustrate + observe + notes)**?
   - This question accounts for physical and handling and subject-object aspects in an activity. It can discuss the affordances of the activities and could cover focus shifts and breakdowns.

3) Did the iPad ever surprise, irritate or help you **(explicate with examples, illustrate + observe + notes)**?
   - This question probes for manners in which the iPad forces pilots to adapt to the iPad or reconsider how to manage goals. It relates to breakdowns and focus shifts and could cover activities in general. It can also indicate how the iPad actually helps to manage/ reach goals.
   - Besides the relevance for the human-artifact model, this question also opens up to discuss situations in relation to the whole JCS.

4) What moments are we supposed to use it and what moments not?
   A) What does this look like in practice?

   - This question starts a discussion on (prescribed, personal, practical) boundaries on when the iPad can or cannot be used. And whether these boundaries come from the users or the designers and help understand when something becomes a breakdown/focus shift.
   - It takes a systems perspective on the JCS, be it prescriptive or descriptive.
   - Avoiding specific activity ('what moments not') also counts as relevant information, since it also has a 'why' (e.g. trade-off of goals).

5) What do you think of the position of the iPad in the cockpit **(illustrate + observe + notes)**?
   - This question relates to tensions in the physical/handling aspects in relationship to the position of the iPad in the cockpit side-window.
   - This question can produce information for the human artifact model, as well as for knowledge on the JCS.

Appendix D: List of Questions with Interview Protocol for Activity Analysis

Interview (probe during the answers about why/what/how):

1) Could you walk/talk me through how you use the iPad in the cockpit (by using appendix A)?
    A) Why do you perform them? What results do you want to see? And how do you make that happen **(explicate with examples, illustrate on iPad + observe + notes)**?
    B) What do you have to say about how this activity integrates with your other duties? (e.g. Do they facilitate these duties? Do they ever compete?) **(explicate with examples)**
    C) Is it new/different compared to our paper era? **(provide examples)**
    D) Does it help you do your job? **(explicate with examples)**

    - This first question starts by checking whether what the SMEs think is worthwhile to tell, and allows them to show what they do.
    - This question relates to the operation of the whole JCS with iPad.
    - I can probe by introducing insights about activities, breakdowns and focus shifts (and their characteristics) from the artifact analysis.

2) Let's move along the flight-profiles (appendix A) while, at each phase, having a look at the activity cards. Are there any activities you performed, or have seen being performed, at these flight-phases which we haven't discussed? **(consider critical activities distilled from artifact analysis)**
    A) Please sort the activities against flight-phase **(register on photo)**.
    B) Why are they performed? What results do you want to see? And how do make that happen **(explicate with examples, illustrate on iPad + observe + notes)**?
    C) What do you have to say about how this activity integrates with your other duties? (e.g. Do they facilitate these duties? Do they ever compete?) **(explicate with examples)**
    D) Is it new compared to our paper era? **(provide examples)**
    E) Does it help you do your job? **(explicate with examples)**

    - This question covers the same material as the first question, however the amount of detail about activity possibilities is increased due to the activity cards.
    - I can also probe if any of the previously mentioned activities ever occur at other moments which were not mentioned before.

3) What happens if this or that changes? (e.g. runway change during taxi out, or parking position at a strange airport). **(Explicate with examples)**
    - This question probes for the manner in which pilots manage the iPad use due to newly introduced circumstances which ask for the JCS to adapt to it.

4) In what way does your use (or that of your colleague) change if there is time pressure due to slots/delay compensation? Feel free to illustrate that by reflecting on the activity cards and flight-profile. If so, what would that look like? **(provide examples, explicate, illustrate on iPad + observe + notes)**
    A) Why does that activity change? What results do you want to see? And how do you make that happen? **(explicate with examples, illustrate on iPad + observe + notes)**

B) What do you have to say about how this activity integrates with your other duties? (e.g. Do they facilitate these duties? Do they ever compete?) **(explicate with examples)**

C) Are certain aspects new compared to our paper era? **(provide example)**

- This question focuses on the change of coordinative use of the iPad in the context of time constraints.
- In asking this question I will help them remember the days during 'busy months', busy roster, busy airspaces, a lot of disturbances.

5) What is disturbing in working with the iPad? **(provide examples, explicate)**

A) What about getting drawn into the iPad, let's say, the iPad needs more attention than expected? **(explicate with examples)**

B) What would be typical moments you bump into this? **(provide example)**

- This question looks for tensions in the iPad use which influences the pilots availability for other tasks.
- For this question I can reflect on results from the Artifact analysis.

6) I experienced …, do you remember such a scenario? Did you ever encounter any dumb or smart use of the iPad with yourself or your colleague or experience a memorable event? **(provide example)**

A) Why was it done? What results did you want to see? And how do you make that happen? **(explicate with examples, illustrate on iPad + observe + notes)**

B) What do you have to say about how smart or dumb this activity integrates with your other duties? (e.g. Do they facilitate these duties? Do they ever compete?) **(explicate with examples)**

- This question probes for tensions which propagate through the JCS after using the iPad, or which are considered to affect the safety margins in the JCS by that form of use.

7) Did your iPad use during work change over time? **(explicate with examples)**

A) Any learning moments or opinions about working with the iPad? **(examples)**

- This question focusses on learning, and thereby on 'learning aspects' which relate to the handling aspects with regards to the iPad and on a larger level to the JCS. It is a way of discussing tensions which presented themselves as a learning opportunity.
- The learning moment presents itself as personal knowledge, after having gone through an experience. This learning is not general knowledge and thus, these tensions remain present in the JCS.

8) Is there any coordination between pilots when using the iPad? **(explicate with examples)**

- This question looks for more information about the management of the cockpit ecology during the iPad use.

9) Were you trained to use it? **(explicate with examples)**

A) Are there clear boundaries in its use? **(explicate with examples)**

- If there has been training in its use, this question helps me find out to what extent I can relate to personae (a typical user) and techsonae (the artifact as tool, and clarified action possibilities by design) and consider certain use possibilities/situations as normal or abnormal or without any category.

10) In general, do you welcome the iPad in your work and is there anything you would improve in its use? **(examples)**

This question is mainly to give them a cool down. But it can also show a general opinion of the iPad, apart from my analysis.

11) Do we need to discuss anything else (e.g. cover some topics) in more depth in your opinion? **(explicate)**
    - The interviewee can, by this question, reflect on what was said and discussed in the interview. The question probes for information that the interviewee deems important related to the subject, or to the interview.

Research questions (assigned codes):

In the table below you can find which research questions can be answered by the interview for the artifact analysis and for the activity analysis.

M-1 In what ways do iPad related activities with its digitizing aspects interact with other coordinative tasks of cockpit crewmembers during flight and how does it influence flights?

S-1 What did flight operations look like before the iPad?

S-2 What does the iPad introduce into flight operations?

S-3 How do cockpit crewmembers and the iPad interact?

S-4 What are the pros and cons for cockpit crewmembers, and for flights in general?

T-1 Applied to a situation where new technology is introduced for which it is ambiguous what activities and functions are introduced and how they interweave with other functions; can activity theory serve as tool to scrutinize the quality of a joint cognitive systems and relate these qualitative aspects back to the introduction of the artifact?

M = main research question

S = sub research question

T = theoretical research question

A = Artifact analysis interview question

I = Activity analysis interview question

	M-1	S-1	S-2	S-3	S-4	T-1
A-1		x	x			
A-2			x	x	X	
A-3	x		x	x	X	
A-4	x			x		
A-5			x		X	
I-1	x	x	x	x	x	
I-2	x	x	x	x	x	
I-3	x			x		
I-4	x		x	x	x	
I-5	x		x		x	
I-6	x			x	x	
I-7	x			x	x	
I-8	x			x		
I-9			x	x		
I-10					x	
I-11						

Appendix E: Tasks with Respect to Interviews

In the invitation I will:

- Invite the participant in a letter
- Ask the interviewee to bring his/her iPad
- Introduce my research and include the informed consent form (Appendix B)

Before the interview I will:

- Introduce myself and explain the purpose and nature of the interview
- Explain my neutral position in the organization and tell about how my study had set me on course to this research topic
- Share my experience of participating in a study of a colleague and me wondering if the data would be really anonymous
- Inform them that any (historical) iPad experience is valid to mention, since our iPads (hardware and software) had many updates
- Brief them about the nature of my study, the voluntary nature of their participation and my role in assuring their privacy
- Leave room for any questions
- Ask them if they read the introductory and consent form (see Appendix F) and ask their written consent for a recorded interview

At the start of the interview I will:

- Start to record audio
- Ask who they are, their position and number of years in the organization. (The SME background tells me a lot about how to interpret what he/she conveys)
- Tell them that the questions relate to their own way of iPad use as well as certain use they have seen or experienced in the 'other seat' (by a colleague).
- Continue with questions (see preliminary questions)

During the interview I will:

- Keep in mind the artifact analysis with regards to possible tensions in the iPad use and critical work situations in the JCS
- Not only focus on the iPad use in their answer, but also on how the other cockpit duties were influenced
- Focus on how they work with the iPad and how they make things go right by asking about how they manage, integrate or adapt to circumstances or learned to work with the iPad
- Include scenarios for when things don't go as planned, after which they have to re-engage with the iPad (e.g. make a new performance calculation, or screen automatically turning off)
- Be aware if something has meat on the bone, e.g. when they express emotions
- Encourage them to share scenario's they can come up with
- If I find they doubt about sharing information I can encourage through examples of ASRS or share experiences of others or my own
- Make notes of observations in how they use the iPad
- Take photos of the activities cards placed against a certain flight-phase.

At the end of the interview I will:

- Ask them if they have any questions
- If they want to add something to what has been discussed
- If I can contact them in case I have questions

Appendix F: Informed Consent Form

Invitation and informed consent form.

Study title: The coordination of iPad related activities during flight, a qualitative, explorative study of the 21st century cockpit.

Researcher: Elie El-Hage, +31618369844

Lund University

Background and purpose of study:

With the introduction of the iPad in the cockpit there has been a transformation of pilot duties and activities on board and in the cockpit. Airlines regard the iPad as a tool that works, but rarely do they ask who make it work. This study is developed to examine what and how pilots manage the demands that emerge during flight operations due to the iPad introduction.

The study will be performed through interviews which will be recorded and the (anonymized) results of this study will be published in a thesis. A summary will be written to present some results to my organization.

Please bring your iPad as it might be used to clarify certain situations.

Confidentiality:

During the interview an audio recording will be made which will be fully transcribed for analysis purposes. The recordings will be stored on the researcher's personal computer to which only he has access. The interviewer will also take notes during the interview. The identity of participants will remain confidential, which means it will not be published in the thesis, neither in the subsequent summary or report. If any reference is made to an interviewee, it will be by pseudonym. GDPR rules are respected and after finishing the thesis the audio recordings will be destroyed. Contributed data will also be removed or destroyed any time a participant requests so. You may refuse or withdraw from the research any time you want.

Consent:

I have read the aforementioned information and I consent voluntarily to be a participant in this study.

Name Participant:

Signature: Date:

Student Researcher Signature:

Signature:

Appendix G

Table A 1

Results of artifact analysis

ASR DATA	ASR DATA	ASR DATA
A1: Below 10.000 (n 35)	**A8**: Pilot difficulty stay in update loop (n 14)	**A20**: Automatic chart change (n 5)
A2: Distracted (in monitoring) (n 34)	**A9**: Info missing/deleted (n 37)	**A21**: Hedonistic use' (n 2)
A3: Coordination propagation (n 31)	**A10**: Zoom/veiled info (n 33)	**A22**: Smoke (n 1)
A4: Swiping during movement/heads down time (n 14)	**A11**: Amount of (auto)updates (n 15)	**A23**: Buzzing sound when touched (n 3)
A5: GPWS/low alt/ speed exceedance (n 11) *	**A12**: Chart management (n 18)	**A24**: Flight mode off during flight (n 1)
A6: Frustration iPad (n 25)	**A13**: Connect (e.g. wifi) issue (n 20)	A25: Late FPLN update (n 3)
A7: Lack of training (in info finding) (n 8)	**A14**: Batt issue/charge/drain (n 10)	**A26**: Mount falling/ issues (n 10)
	A15: Freeze/crash (n 29)	A27: iPad restricts steering (n 8)
	A16: iPad enters sleep mode (n 1)	A28: CB tripped due to mount (n 1)
	A17: Locked out app/iPad (n 13)	**A29**: Adjusting brightness (n 2)
	A18: iPad goes off automatically (n 9)	**A30**: Blocks view out of window (n 2)
	A19: Typing during turbulence (n 4)	**A31**: Night vs day mode iPad info (n 3)
		A32: Wrong Performance (results or database) (n 15)

*Besides GPWS, too low altitudes and speed exceedances, other incidents occurred as well and are included, namely: upset, rwy incursion, Late descent, egpws, track deviation, wrong turns

(n) – indicates the amount of reported occurrences that were gathered under the related category

Bold font code: can be found back in the artifact cards in phase 2

About iPad:	Documents Data – Software Data	– Hardware Data
Ph1: Glitch (charts jump around)	**Fu4:** Flightmode	**Fu22:** database (actuality)
Ph2: Elec shock **(NA)**	**Fu5:** Auto rotate screen	**Ap1:** ID app
Ph3: Incomplete data/ info **(NA)**	**Fu6:** Sleepmode	**Ap2:** Weather app
Ph4: Buzzing noise	**Fu7:** In app buttons	**Ap3:** E-mail app **(NA)**
Ph5: Change of info location	**Fu8:** zzz vs z-z-z	**Ap4:** Roster app **(NA)**
Ph6: Falling (iPad) **(NA)**	**Fu9:** Day/night mode **(NA)**	**Ap5:** Reporting app
Ph7: iOS problems/abnormalities	**Fu10:** Update/ Downloading	**Ap6:** Performance app
Ph8: Slow ipad	**Fu11:** Brightness	**Ap7:** De-Ice app
Ph9: Crash	**Fu12:** Camera	**Ap8:** General Flight Info app **(NA)**
Ph10: Smoke/fire	**Fu13:** Music	**Ap9:** Flightplan app
Ph11: Freeze	**Fu14:** Games	**Ap10:** Company News app **(NA)**
Ph12: Loose in mount **(NA)**	**Fu15:** Mobile data connection	**Ap11:** Charts/Manuals app
Ph12: Overheat **(NA)**	**Fu16:** Charger	**Ac1:** Battery management
Ph13: Difference in data/info	**Fu17:** Mount **(NA)**	**Ac2:** Chart management
Ph15: Locked out of app	**Fu18:** Airdrop **(NA)**	**Ac3:** Charging
Fu1: Login to apps **(NA)**	**Fu19:** GPS location	**Ac4:** Zoom in/out
Fu2: Login to iPad	**Fu20:** Backup procedures **(NA)**	**Ac5:** App management
Fu3: Passwords	**Fu21:** Documents/manuals	**Ac6:** Typing **(NA)**

Ac7: Turn screen on **(NA)**
Ac8: Swipe (e.g. flight app)
Ac9: Other management? **(NA)**
Ac10: In app switching

Ph – Phenomenon Fu – Function Ap – App Ac - Avtivity

Normal font: not used for interview

Bold font: used for the interview

(NA) immediately after the artifact interview it was decided this code would not be used for further research

Table A 2

what to take from artifact analysis to the activity analysis)

Possible concepts/themes to keep in mind interpreting next interviews

Artifact as imagined

Sacrifice decisions (start work in hotel/taxi, glitches, short turnaround check next flight, do/don’t use certain apps)

(Un)distributed cognition (mpilot updates vs paper updates, iPad use, notes of departure/n-1 on paper)

Learning/training/affordances (new apps require more effort, learning to work with them)

Non-specified activities, non-formal activities

Uncoordinated activity (delegating, notifying about iPad use)

Shortcuts (book structures and content vs search function)

What counts as knowledge (regarding processing updates)

(Compression of) time (more work in less time, e.g. amount of apps, turnarounds are shortened)

Notions of boundaries (when iPad use related activities no longer happen)

Eyes off cockpit instruments

Non determinism in design

Variability in design, unexpected praxis, unexpected tensions

Unexpected interactions after design (incorrect flex temp in open apps overview screen), non-reproduceable.

Certain iPad functions change formally agreed colours in map (grid alt)

Collecting information during taxi-in for next flight due to short time on ground

Relevant

R1: Reporting

R2: Troubleshooting

R3: Knowledge (of updates)

R4: Listening to music and gaming

R5: Sorting/finding charts

R6: Charger (falling out), charging

R7: iPad management (approach/take-off)

R8: iPad use during manual flight/taxi, handling technique?

R9: Chart management, swipe, tap, zoom, pan

R10: Critical information retrieval during critical circumstances (e.g. altimeter transition altitude, or autopilot off and scanning charts)

R11: Notion of progress (e.g. auto sleepmode ~ zzz, swipe charts)

R12: GPS use

R13: De-ice app

R14: Shortcuts in iPad use by handgestures

R15: Handgesture input can fail and requires new try

R16: Engage flightmode

R17: Learn to work with new app where to find info (quick glance vs active search/ unconscious vs conscious activity)

R18: Aging of hardware (slow/full harddisk)

***Glitches in apps – see troubleshooting as related activity**

RGl1: Apps Lockout/Password reset

RGl2: Unresponsiveness

RGl3: Wireless data access

RGl4: Jumping charts

RGl5: Crashing apps

RGl6: Incomplete info

RGl7: Auto sleepmode engagement

RGl8: Buzzing nois

Less relevant

Lr1: Forgetting to fill in or finalize flightplan

Lr4: Use mobile phone as hotspot

Lr7: Skills for trivial apps (wx ap)

Lr2: Mount positioning (e.g. horizontal/vertical)

Lr5: Incomplete downloads

Lr3: Autorotate not responding well

Lr6: Dark mode activation

Table A 3

Period before and period after the iPad

iPad vs paper

iPad aspects

- Search function
- Updating automatically
- Easy access of information
- Non authorized functions (GPS) +
- Games +
- Music +
- Charging +
- Facilitates making digital notes on charts

Paper aspects

- Search content by structure of books
- Manual updating by sorting papersheets
- More effort to access information (flightbag)
- No GPS/games/music
- No charging
- No zoom option.
- Notepad present on which departure/arrival information was processed.

+ stands for (possibly) added into the system

Praxis with regards to changes, found during interview?

Prax1: Updates are processed by reading the summary of most important changes on the front page of the book, rather than reading every page in full context or are not processed immediately or not at all.

Prax2: Making the scan through a flight a moment together, sharing knowledge is gone (Ref: **Snook, eat and drink together**) --- layer in which info is lost?

Prax3: Retrieve flightdata in hotel/taxi.

Prax4: Paper flightplan info was more tangible, also for notes (filling in and finalizing flightplan was remark from IL&T)

Prax5: No necessity to go inside for printing.

Appendix H

Activity analysis – formal documentation: iPad use in the cockpit ecology

Overview work-as-prescribed from documentation

Use Boundaries:

Malfunction influencing flight operations: call operations. - Non consistent info: use newest info. - ***Only Apple charger***, and never charge during lightning. - *Update only after company announcement. -* EFB apps must be up to date before flight, OFP before every flight, performance daily. - ***Longer periods of use: out of mount. -*** Charging cable may not impair flight. - Charged sufficiently before flight. - Stow in mount during critical phases and when not used, also during non-critical phases. - ***PNF normally operates iPad. - PF use of iPad only when workload allows. - Transfer controls during extensive use periods***. - ***Keep minimum interaction with iPad during high workload. - Avoid fixation on display, or distraction from primary duties. - Apps not relevant for flight not allowed. - Don't use GPS. - Portable elec equipment poses risk on fire and interference. - EMI regulations are applicable to both pax and crew. –*** Mobile phones and mobile devices can pose threat (distract crew e.g.). - They may only be used regarding flight execution duties. - ***Wireless data transmit/receive may be used if necessary, in any flight phase and with consideration to threat of distraction and safety critical tasks.***

Flight mode is not obligation for crew when it has to do with flight execution

Weather app: only use for long term strategy, primary sources overrule app, avoid use in high workload situations.

Sterile flight deck

Guarantee an **undisturbed working environment**. To create a sterile flight deck the flight crew should:

Remove or stow any loose articles (adapter??);

Refrain from 1 - duties other than those required for the safe operation of the aircraft; ***2 - any activity that could distract any flight crew member from the performance of his duties*** or which could interfere in any way with the proper conduct of those duties; Limit the exchange of information with the cabin crew to procedural calls/replies, safety and security issues;

Limit intra-flight deck communication to the necessary communication for the operation of the aeroplane and the proper conduct of duties.

Critical phases of flight

Means at least the take-off run, the take-off flight path, the final approach, the missed approach, the landing including the landing roll and additionally any phase of flight as determined by the commander. During these critical phases of flight the 'sterile flight deck' concept shall be maintained. In case of 1 iPad do not use it during ***critical phase of flight***: take-off run, take off flight path, final approach, landing (incl rollout). In one manual**: critical phases of flight *includes taxi procedures***.

Take-off and climb

For take-off and initial climb the altimeter shall be set to the aerodrome QNH. During climb the altimeter shall be set to the STANDARD setting when passing the transition altitude.

The active FMS flight plan is checked by comparing charts, or other applicable documents.
An airport diagram should be readily available to each crew member during taxi.

During taxi:

Progressively follow taxi position on the airport diagram; The Pilot Flying (PF) calls out taxi intentions approaching relevant taxi-way intersections or directional options to enable the Pilot Monitoring (PM) to verify correct taxi routing;

Phases of high workload:

From off-blocks until 10,000 ft above the departure aerodrome and from 10,000 ft above terrain or landing altitude (whichever is higher) until on-blocks. During these phases the **'sterile flight deck'** concept should be maintained.
During all phases of flight each flight crew member required to be on flight deck duty shall remain alert and maintain **situational awareness**.

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