

A Multi-Cultural Study of Paper Use in the Flight Deck

Saeko Nomura **Edwin Hutchins**

Cognitive Science Department
University of California San Diego
9500 Gilman Drive

La Jolla, CA 92093-0515, USA
saeko@hci.ucsd.edu, ehutchins@ucsd.edu

Barbara Holder

Flight Deck Concept Center
Boeing Commercial Airplanes
PO Box 3707

Seattle, WA 98124-2207, USA
barbara.e.holder@boeing.com

ABSTRACT

It has been proposed that computer-based technologies will soon replace paper documents in the commercial airline flight deck. This article describes the nature of paper-use practices in the present-day flight deck. We hope that an improved understanding of the roles currently played by paper documents will contribute to more effective design of the systems that will replace or complement them. To this end, we conducted a series of ethnographic studies at airlines in Japan and New Zealand. Our research shows that work practices involving paper play a role in the planning of information access, the management of attention, and the establishment and maintenance of shared understandings between pilots. We anticipate that in the future paper will not be regarded as just a vestige of earlier practices that has somehow continued to survive, but rather will be an integral feature of new technology systems.

Keywords

Paper-use practice, the electronic flight bags, Electronic Checklist, ethnography, multicultural study.

INTRODUCTION

Commercial aviation is currently at a crossroads with respect to the use of paper in the flight deck. Emerging computer-based technologies promise to provide flight crews with additional support. Among the proposed systems are devices that go by the names, “Electronic Checklist” (ECL) and “Electronic Flight Bag” (EFB). These names suggest computer-based versions of paper document collections. The use of such metaphors in HCI often creates design spaces in which researchers list the tasks that are supported by existing technologies, and then attempt to build support for those same tasks in new technologies [13]. An alternative approach to the development of future flight deck systems is to examine actual practices and identify the cognitive functions that are created or regulated by the practices. For example, current flight deck practices manage the access to information and the allocation of attention. They regulate the depth of processing of information and the establishment of shared understandings. In addition to these task-related cognitive functions, there are “intangible” factors [19] that are less likely to appear in a task analysis. For example, current paper-use practices also help to establish and maintain social relations and personal identities. Whatever design methods are used, they should be alert to the possibilities of improving support for these functions in new technological systems.

A number of researchers in CSCW and HCI have discussed the use of paper documents in various kinds of work settings [8, 9, 17, 19, 21, 23, 24]. In these studies, the advantages and affordances of paper such as flexibility in spatial layout, ease of manipulation, possibility of direct marking, awareness or ‘at a glance’ nature, physicality, and so on have been highlighted. Although the flight deck is the pilots’ office, it has different characteristics from other work settings where paper plays a central role. For example, flight deck work is high-stakes and high-tempo activity. The flight deck is more isolated from its surroundings than its terrestrial counterparts. It is a small space and operators cannot move about. This means that display space is very limited. Because it moves, every extra gram of weight carried in an airplane must be paid for in extra fuel consumption. Consequently there are economic pressures to eliminate or reduce the amount of paper carried in the flight deck [1, 7] and concerns about the consequences of its elimination or reduction have been voiced [25].

There is no doubt that ECLs, EFBs, and other similar systems have an important role in flight decks of the future. Manufacturers and operators are already exploring the range of applications for this sort of technology. The evaluation methods and tools for EFBs usability have also been discussed [2, 3, 4]. However, few research findings, based on ethnographic observation [11, 12], describe how pilots use paper in everyday operations in the global airline flight deck.

We are now in the early stages of a worldwide investigation of the roles of language and culture in commercial airline flight operations. Since language appears in the flight deck in many forms, including on paper, the use of paper has been a focus from the beginning. In this article we will describe the practices of paper use in the flight decks of three airlines. We will then reflect on the observed patterns of paper use and suggest some ways to anticipate the consequences of replacing or augmenting paper documents with computer-based tools.

RESEARCH METHODS

We conducted a series of field research studies at three airlines in 2005. Our methods include direct observations from the observer’s seat in the flight deck during revenue service, observation and videotape of pilots flying in full-motion simulators, and interviews with “line” pilots about their work practices. Our flight observations took place in Boeing 777, 747-400, and 737-300 airplanes. The simulator

Table 1: Summary of research subjects.

Field Sites	Revenue Flights		FSS Trainings	
	Number of flight segments	Number of pilots observed	Hours observed	Number of pilots observed
Japan	22	22 pilots	15 hours (10 hours of simulator and 5 hours of brief/debrief)	7 Japanese pilots (3 captains and 4 first officers)
North America (Japanese airlines)	---	---	37 hours (26 hours of simulator and 11 hours of brief/debrief)	3 Japanese pilots (3 Japanese captains)
New Zealand	21	14 pilots	4 hours (2 hours of simulator and 2 hours of brief/debrief)	2 New Zealand pilots (1 captain and 1 first officer)

sessions were conducted in the Boeing 777. All observers gathered before the sessions and after the observation sessions, to plan the day's work and to reflect on what had been observed. In the three field trips in 2005, our research team observed more than 40 segments of revenue flight and recorded more than 50 hours of video data in flight simulators (See Table 1).

The ethnographic approach used in this study has some advantages over surveys and interview-based research strategies. However, it is also relatively expensive and requires a great deal of technical expertise. Among the chief advantages is the fact that ethnographic observations directly access pilot behaviors as they occur in social, cultural, and organizational context. When one is interested in the behaviors of pilots, there is no substitute for observing those behaviors directly. Furthermore, while our research team was able to anticipate many of the phenomena we observed, we also encountered a number of surprising things that we never would have asked about had we not make direct observations in flight. The surprises described below include hand-drawn annotations to approach procedures and a document archive crafted from a left over lunch box. It is a common misconception to assume that the primary contribution of ethnographic research related to HCI will be the specification of implications for design [6]. Sometimes, ethnographic work can do that, and we hope that our studies will. But ethnography is really something else; a way to come to understand how people render their activities meaningful to themselves and to others.

A major disadvantage of the ethnographic approach is that it is very expensive in terms of researcher time. Effective data collection requires the researchers to establish rapport with the research subjects. It also requires high levels of technical expertise. Fortunately, we were able to assemble a unique research team that includes technical pilots, flight deck human factors specialists, a cognitive anthropologist, and a native Japanese HCI researcher. The analysis of ethnographic data is also very time consuming. Understanding and interpreting patterns of behavior of pilots from other cultures requires a deep knowledge of the language and culture involved. Transcription of video and audio recordings is only the first step in the analysis process. The segment of transcribed (and translated) interaction reported in this paper represents only

about thirty seconds of crew behavior. We have transcribed many hours of such behavior.

Revenue Flight Observations

We shadowed the appointed pilots through their work day. We often met with pilots at the operations office at the airport, where they checked weather and flight plan information (both outbound and inbound flights). We observed the interaction among pilots and a human dispatcher or a computer-based dispatch system. We also conducted informal interviews with pilots while we walked with them from the dispatch office to the aircraft. In Japan, after boarding the aircraft with the pilots, we remained in the business class area to observe interactions between flight crew and maintenance personnel. We participated in a crew briefing held before the departure among cabin attendants and pilots in the business class area. After that, and with the captain's permission, we entered the flight deck, installed ourselves in the observers' seats, and began observing pilots' activities. We took extensive written notes, captured digital still images, and collected copies of all of the flight paperwork. We used earphones to listen to radio and interphone communications between pilots and air traffic control (ATC), company, and cabin crew.

High Fidelity Flight Simulator Sessions

The full-flight simulator provides pilots with a precisely replicated flight deck that simulates the actual airplane. We recorded flight deck activity using multiple video cameras

In Japan the training was conducted in the pilots' native language (Japanese). We also participated transition training for three Japanese captains at a training center in North America. Because the instructor in this training was a native English speaker, this training was conducted in English. The pilots of the airline in New Zealand are native English speakers and all training observed there was conducted in English.

Interviews with Pilots

At each airline we conducted a structured interview with company line pilots, technical pilots, and instructor pilots or check airmen. The interviews focused the discussion on pilot practices, design considerations, and pilot background and training. We discuss how pilots use the features and functions in the flight desk (including paper) to support flight operations.

PAPER USE IN THE FLIGHT DECK

Variety of Paperwork and Physical Locations

Paper Brought to the Flight Deck

At the observed airlines several pages of paper are carried to the flight deck by the flight crew, or are given to the pilots by maintenance personnel prior to pushback. These papers usually include 'crew information', 'dispatch release', 'passenger list', 'airport information', 'special load', and 'NOTAM (Notice to Airman)'.

Pilots also carry their own flight bags on board. The flight bag may contain aircraft operating manuals, airway route manuals, and Quick Reference Handbooks (QRH). The route manual is a thick binder containing aeronautical charts (Jeppesen charts) such as airport maps, and approach and departure charts. Pilots remove needed charts and maps from the binder according to the flight phase. The QRH contains procedures to follow in case of a non-normal condition, such as an engine failure or electrical system failure. In airplanes equipped with ECL, the QRH is a manual backup for the electronic checklist.

Crew Generated Papers

In the flight deck, there is a small printer, called the ACARS (Aeronautical Communication Addressing and Reporting System) printer, located in the center console. ACARS is a digital data link system that allows airline flight operations departments to communicate with the various aircraft in flight. During the course of a flight the crew receives messages and prints them out on small slips of paper. On a routine one hour flight, pilots print from 6 to 15 messages depending on how quickly the information is expected to change. The printed information often includes aircraft weight and balance, take-off runway, flight weather, airport weather, and landing runway.

Pilots often take notes during communication with people outside the flight deck. A small scratch pad and pens are used to write down a variety of information such as: flight number, actual arrival time, runway number, gate number, and final passenger count. Complex, multi-element clearances from ATC are also written on these note pads using a shorthand notation. Out of date information is crossed out and new information is written on the same page. One sheet was used per flight segment.

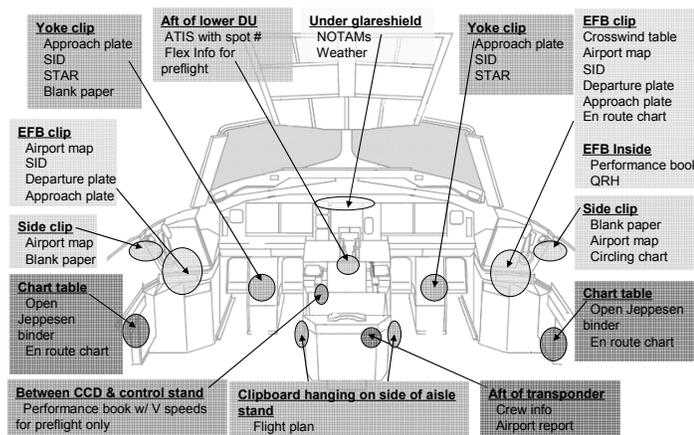


Figure 1: Spatial layout of papers in the flight deck.

Spatial Layout of Papers in the Flight Deck

Papers are distributed throughout the flight deck during the flight. Figure 1 illustrates the observed locations of various papers in a Boeing 777 during a short flight.

For the observed flights pilots usually placed airport maps, standard instrument departure charts (SID), standard approach charts (STAR) on a yoke clip, a clip located where an EFB could be installed (EFB clip), and a side-window clip. An en route chart (low altitude flight plan map) is allocated either on an electronic flight bag clip or on a chart table. The Jeppesen binder opened to the next needed chart and personal notes created by pilots are placed on a chart table. The scratch pad is provided by the company and is placed on the side window clip. Two pilots usually have the same charts available and organized similarly on each side.

Across all observations, pilots reorganized the spatial layout of papers during the flight according to the flight context. For example, prior to the take off, a map of the departure airport and the hand-written departure clearance copied from ATC communication are placed on the side clips, and a departure procedure chart is located on the yoke clip. Pilots change these documents into an arrival configuration during the cruise mode. Prior to descent the crew organizes their charts with the arrival procedure laying on the flight bag, airport map on the side, en route chart below the airport map, and approach plate on the yoke.

At some airlines, dispatch release documents were put on a clipboard and hung on either side of the aisle stand in center of the flight deck. If the pilot monitoring (PM)¹ was to monitor fuel amount during the flight, the clipboard would be hung on the side of the pilot monitoring. NOTAMs (Notice to Airman) and weather information are slipped into a pocket under the glareshield. Other dispatch papers such as crew information and airport report are typically placed on the center console behind the transponder.

The latest printed out ATIS (Airport Terminal Information Service) message is typically placed in a location that easy to access by both pilots, for example, between the pilots, on the center console, in front of the thrust levers, or impaled on a switch on the instrument panel (in the 737), depending on the airline and airplane type. On the arrival airport information ACARS printout, pilots handwrite a gate number. When pilots replace an ACARS printout with an updated version, the old one is archived by moving it to around the communication radio interface, just on the dispatch paper filled with cabin crews' information, or in a small box crafted from a left over lunch-box placed after of transponder.

Practices of Paper Usage

Throughout the flight, paper plays important roles in crew coordination, message confirmation, note-taking, and information affordance. In this section, we describe how pilots use papers with an effective combination of other artifacts

¹ The flight crew is composed of a Captain and a First Officer in two crew airplanes. Either pilot may assume the role of pilot flying (PF) or pilot monitoring (PM). The PF manipulates the flight control and flies the aircraft. The PM supports and monitors the PF.

such as flight deck equipment, computer displays, and the gesture and language they bring about.

Crew Coordination

For the observed flights each segment begins in the operations office. Here pilots receive and review the dispatch papers for the flight. At one Japanese airline, the dispatch paperwork is presented to the two pilots by a dispatcher who has compiled and annotated the documents. The flight crew stand on one side of the table and the dispatcher stands on the opposite side facing the crew. The paperwork is placed on the table in front of the captain oriented so it is right side up for him, and upside down for the dispatcher. The crew then discusses the papers with the dispatcher. This discussion is enhanced by a sequence of pages (graphical depiction of en route weather, for example) presented on a computer display located at the end of the table. The dispatcher uses previously-made annotations and highlighting to direct the captain's attention to important elements in the paper documents. The captain signs a copy of the dispatch paperwork to confirm his approval of the dispatch work. The other dispatch documents that the crew must bring to the aircraft are collected by the first officer. The tangible nature of paper documents allows the crew to enact the social organization of the crew in their handling of the documents. Japanese first officers often asked their captain for permission to collect the papers at the end of the briefing. The first officer then puts the papers into a transparent file which he had prepared for this purpose.

After arriving at the aircraft, pilots and cabin crew gather at the business class area to have a crew briefing. The cabin attendants line up along the aisles and behind seats two rows back. The captain holds dispatch papers and cabin crews bring their personal small memo pads and a pen. After a brief self-introduction from each member of the crew, the captain reads from the dispatch papers informing the cabin crew about en route weather and the number of passengers who needs medical assistance. Members of the cabin crew nod to exhibit their comprehension to the captain and take notes during the briefing.

Before dispatch, the captain signs the aircraft maintenance log, signs the fuel slip and hands it to the fueler, and after the last flight of the day, he signs the first officer's flight log book.

Paper Supported Data Entry

Paper has an important role in establishing patterns of coordination between pilots. During the pre-flight phase, pilots load data into a FMC (Flight Management Computer) via a user interface called the CDU (Computer Display Unit). Pilots access information that appears on dispatch papers and ACARS printouts. Pilots then do a procedure to carefully cross-check the route. The PF has the route displayed on his CDU, and PM holds the navigation paperwork. They step through the route one waypoint at a time confirming that the route in the FMC corresponds to the route specified on the flight plan. ACARS (Aircraft Communications Addressing and Reporting System) messages are also requested through the FMC. ACARS is used for requesting the takeoff thrust information for the runway in use and final weight and

balance before the departure, weather information for the flight route and destination, the latest arrival time of arrival airport, and so on. When final weight and balance information arrives via ACARS, the captain reads out the information on the paper and the first officer inputs it to the FMC. For example, a captain called out "348900" while the first officer entered Gross weight 348900 on his CDU. Note that critical numbers such as gross weight are printed on the paperwork both as numeral and as words: "THREE FOUR EIGHT NINE ZERO ZERO" to avoid read-out mistakes. After that, both pilots jointly review the data on the CDU to ensure it is correct. The manual review of flight critical information that could be loaded automatically into the flight computers is a common practice that is supported both by the design of interfaces and by airline policies.

Cross-Reference of Data on Paper

Pilots must confirm the accuracy of certain types of information through multiple data sources and representations. For example, on takeoff, the crew must know the speed at which it is no longer possible to stop the airplane on the runway (V1), the speed at which the nose wheel should be lifted off the runway (Vr) and the speed at which the main landing gear should leave the runway (V2). Once the basic performance data have been entered, the FMC can and does compute these V-speeds. However, the computed speeds are not immediately made active for the other systems (displays, for example) that use them in flight. The pilots are required by the FMC interface design to review and select these speeds one at a time. This design reflects a tradeoff between speed of execution and the depth of cognitive processing for the pilots. Many airlines require their pilots to interact even more closely with these critical speeds.

In one airline in Japan, pilots check V-speeds by comparing three sources of information. In the flight deck, pilots have V-speeds computed by the FMC and displayed on the CDU, V-speeds computed by company dispatch printed out via ACARS, and V-speeds as they appear in the flight operation manual. At one airport where the runway was wet, they compared FMC to dispatch V-speeds. The captain instructed the first officer to get out the flight operation manual and they discussed how wet the runway actually was. They decided that it was not very wet and they accepted the FMC computed speeds, which were identical to the dispatch computed speeds.

At the airline in New Zealand, pilots are required to compute takeoff V-speeds using a form called the Performance Takeoff Certificate (PTOC) (See Figure 2). Pilots use printed performance tables to look up the values that are to be entered in the spaces in the PTOC form. Here, weather and weight, runway, and performance information are retrieved from ACARS, airport chart, and flight operation manual, respectively. After completing the form, the PM places the PTOC in the performance table book on the page where the relevant data is located. The book and PTOC are then passed to the PF, who checks the computations. After that, data are input to FMC through CDU. The pilots then fold the PTOC so it can be placed in a prominent place in the flight

deck and confirm the display of V-speeds on air speed indicator (ASI).



Figure 2: Cross-reference of paper work: use of PTOC.

These paper-based practices force the pilots into interaction with the V-speeds and the information on which they are based. The practices increase the depth of processing of parameters that must be correct for safe flight. They facilitate shared situation awareness and memory.

Figure 3 is an example of paper distribution at the captain's seat during an approach. These documents were arranged like this prior to commencing the approach. Pilots are required to plan and prepare the access to information in advance so that they can stay 'ahead of the airplane' [16] as its position and operational context change. An en route chart is on the EFB clip at the captain's lower left. The chart for the approach to be flown is positioned on top of the en route chart. The destination airport map is on the yoke clip, and the taxiway map (with gate numbers) and a notepad are placed on a side clip below the left window. A Jeppesen binder opened to a page containing hand-written annotations is on the chart table to the pilot's left.



Figure 3: Paper distribution at the captain's seat in approach-taxi session.

During an approach, a pilot must imagine and plan the path of the airplane from many miles out down to the runway, and then to the arrival gate. Pilots scan across these multiscale representations in order to imagine the location of their aircraft during this high-workload phase of flight. Because

large airports can have complex runway and taxiway configurations, and because landing requires all of a pilot's attention resources, pilots need to determine before landing the taxi course they will take after landing. So, they consult the en route chart (for space scores of miles out), approach charts (spatial and numerical representations out to about ten miles), and the destination airport maps (the immediate environs of the airport and the airport surface). In addition to the cross-referencing the paperwork, they also check the current weather information with ACARS printout, radar weather depiction on the navigation display, and the computed flight path represented on a navigation display to confirm the current conditions. Here, pilots coordinate static representations that are printed on papers with the current conditions as depicted in digital representations. As the aircraft draws near to the airport, the crew performs the approach briefing. Both pilots refer to the approach chart while they review and confirm the runway number, approach course, glide path, navigation radio frequencies, missed approach procedures, landing visibility requirements and so forth. As was the case with the takeoff briefing the pilots establish coordination among elements of information on a complex set of paper and digital displays.

Reading vs. Listening to the Speech

Many Japanese find written English easier to understand than spoken English. This may be due in part to education systems that emphasize English reading and writing skills over speaking skills.

At some airlines, when two pilots do a procedure together, the PM reads the procedure while the PF executes the actions described. Some airplanes are equipped with an Electronic Checklist (ECL), which is presented on a display in the center of the flight deck. The checklist steps are presented in English and they are read in English by the Japanese crews. We observed many cases in revenue flight and in the simulator in which both pilots read the ECL together. When Japanese pilots used a paper checklist, the pilot reading the checklist leaned toward the other pilot and placed the paper checklist in the line of sight of the other pilot. Both of these practices make the written representation available in addition to the



Figure 4: Written English is easier to understand than spoken English.

spoken representation (See Figure 4). Among other effects, this practice provides the second pilot with a representation of the procedure that is less foreign than the spoken representation. This pattern of behavior is also observed in mono-lingual English flight decks where it seems to facilitate the establishment of common-ground understandings [5].

Document Personalization

Many Japanese pilots annotate their own charts and flight manuals using highlighter pens and colorful sticky notes. Highlighter pens are used on monochrome charts. For example, the runways and landmarks or obstacles near the airport are often highlighted on airport maps. In addition, navigation radio frequencies, final approach course, altitudes at waypoints when on glide path to the runway, and decision altitudes for the missed approach are highlighted on approach charts. Highlights draw pilots' attention to the specific numbers and letters on charts, and facilitated search for an appropriate chart from a thick Jeppesen binder which carries hundreds of pages of similar looking charts. So, the advantage of annotation on the page is immersion in the document contexts and visual search. Colorful sticky notes are used for temporary messages and/or very important messages which should catch pilot's eyes very easily (See Figure 3).

While this practice is present in all of the pilot populations we have observed so far, it seems to be especially important for pilots who are not native speakers of English. The charts are composed of graphics and numbers and language, and the language is English.

Figure 5 is a heavily annotated hand-drawn representation of a complex instrument approach that was prepared by a young Japanese first officer to be reviewed just prior to flying the approach. Japanese pilots, especially young first officers, often review the flights of the day after they arrive at home. They bring all paperwork created in the flight back home and run through the operation of the day, especially for flight patterns in difficult approaches.

Since I have just become a first officer on this particular aircraft, I am learning the maneuvers from the captain during the service. I try to collect all paper documents from the flight and simulate it from departure to landing at home. I use charts, ACARS messages, dispatch papers, and memos which I created during the service, and flight operation manual for the review. [A young first officer]

The document shown in figure 5 is a microcosm of the language ecology of the Japanese flight deck. The annotations are a complex mix of English and the pilot's native language. Character strings that appear in English on navigation charts or flight deck displays while flying this approach are rendered in English. Required callouts and expected communications with ATC that must be produced in English while flying the approach also appear in English on this document. Commentaries, interpretations, techniques, and discussions of tricks and traps are represented in the pilot's native language.

It is important to note that the routes, airports, and procedures depicted in these customized documents are routinely flown and are familiar to the pilots. The pilots reported that the annotations and home-grown notes support study and maintaining familiarity with the information.

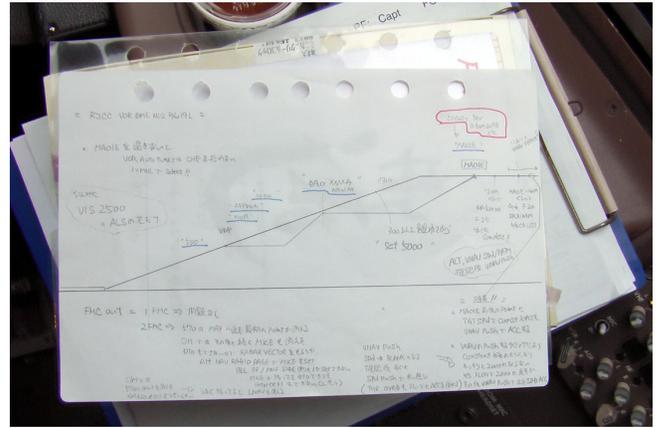


Figure 5: Document customization using color and pilot's native language.

DISCUSSION

Papers are organized in the flight deck by temporal relation to the current flight phase. Sellen and Harper [23] refer to a spatial arrangement of documents that encode the immediacy of use, metaphorically, in terms of hot, warm, and cold documents. Pilots spread out papers and keep 'hot documents' in their field of vision. The yoke clip, side window clip, and EFB clip are easily seen and ready to hand. Pilots are also surrounded by 'warm documents' and 'cold documents' in the flight deck. Warm documents are placed in the under-glareshield shelf, on a clip board hanging on the side of the aisle stand, behind the transponder panel on the center console, rolled up outboard of the side window clip, in a self-made archive box placed in near the transponder panel, and on a chart table near the pilot's hip. Cold documents are kept in the Jeppesen binder (because these charts are maps for airports unrelated to today's flight), the flight bag, and in a number of storage cubbies located within reach of the pilot seats. The organization and layout of paper help the pilots organize and structure their work. This arrangement makes information immediately available, accessible, and shareable. The nature of paper documents that have been documented in other settings [17, 19, 20, 21, 22, 23, 24, etc] also play potent roles in the flight deck.

'Flexibility' of Paper

The *flexibility* of paper enables pilots to cross-reference and coordinate multiple representations. Pilots use binder clips and switches, that are *not* designed as paper holders, efficiently to array papers around themselves. Cross-reference occurs when pilots extract information, confirm the consistency of information, and integrate information across multiple representations. For example, when pilots enter performance data into the flight management computer (FMC) before takeoff, they refer to several dispatch documents and an ACARS printout to extract numerical information. Pilots confirm the consistency of information across multiple independent data sources in collaboration with each other before activating that information in the FMC.

The event-driven nature of flying requires pre-planning of information access. When pilots prepare for an approach, they make decisions and imagine the trajectory ahead of them. If

the information is on paper, specific sequences of information retrieval can be supported by deliberate arrangements of multiple paper documents.

When non-native English speakers perform checklist procedures in English, both pilots tend to keep their eyes on the text. Since paper is flexible to handle, a pilot monitoring (PM) can lean toward his co-pilot and place the checklist to the line of his sight. This action facilitates the establishment of common-ground understandings between pilots. Since the PM can position the checklist to accommodate the visual needs of the pilot flying (PF), the PF may not need to turn his eyes as far away from affected equipment or the windscreen as would be required by a fixed location electronic display.

'Tangibility' of Paper

The *tangibility* of paper permits pilots to use it in micro-rituals that makes the social organization of the flight deck visible. For example, the physical handoff of the dispatch documents from a dispatcher to pilots facilitates the reliability of the information flow. In addition, the physical handoff of paper documents between pilots provides a means for enacting the social relationship between them. In Japan, when an artifact is handed from lower social status person (the first officer in this case) and higher status person (the captain), the lower status person holds the artifact with two hands and bows slightly when he passes it to the higher status person. In the operations office, dispatch papers are placed facing to the captain while a dispatcher explains the day's flight conditions. And after the dispatch briefing is over a first officer asks his captain politely if he can collect the papers to bring to the aircraft. Thus, handling tangible artifacts in collaboration allows pilots to reconstitute the social order.

The tangibility of the paper clarifies the locus of responsibility for the flight. For example, the captain's signatures on dispatch papers, the maintenance book, and a first officer's flight log book signify his responsibility for the information contained in the documents. In the crew briefing which is held in the business area, the relative locations of pilots and cabin crew and the kinds of paperwork that each has in hand also signify the social organization and the flow of information among the crews.

'Customizability' of Paper

The *customizability* of paper supports pilots' cognitive activities. Some pilots heavily highlight, apply sticky notes, and add comments on paper charts and flight manuals. Highlighting the existing messages facilitates pilots' search and understanding of the document contents. Handwriting comments on the charts and creating original charts maintains familiarity with the airport and route which they fly routinely. This is more obvious for non-native English speaking pilots. Since Jeppesen charts and airport maps are all written in English, non-native English speaking pilots use sticky notes to add flight tips written in their native language to support their comprehensions of the procedures. They also create their home-made charts and tables on weight and balance and approach procedures and file them on their Jeppesen binder. These personal notes are written in with an effective

combination of their native language and English (English is used for flight technical terms).

Annotation is not always directed to oneself. Highlights and hand written notes are applied to dispatch paperwork by dispatchers for the benefit of pilots. The appropriate application of annotation provides the dispatcher with a way to demonstrate professional competence. Instructor pilots sometimes add highlighting to the flight training manual to help student pilots attend to important information. These annotations lead pilots' eyes easily to the distinctive information and support attention as a social event when documents are jointly viewed.

The customizability of paper also allows pilots to take notes during the flight. Pilots (especially PM) often take notes while communicating with air traffic controller (ATC). They write down flight number, runway number, taxiway route number, arrival gate number, actual arrival time, and so on. Handwritten notes are used as an external memory of pilots and assure accurate information flows between pilots, among pilots and cabin crews, and between a pilot and ATC in communication.

'Portability' of Paper

Finally, because of their *portability*, paper documents can maintain the continuity of pilots' experience. The dispatch papers bridge the pilot's experience from the interaction with a dispatcher on the ground, to the interaction with cabin crews in the airplane, to flight operation and the interaction with his co-pilot in the flight deck, all the way to study and review at home. Young Japanese pilots are especially likely to collect paperwork at work and bring it home for review. In the review session, the time stamps on printed ACARS messages help pilots to remember the flight contexts and maneuvers which he or his co-pilot took at that time. Dispatch papers with his handwritten annotations give him accurate numerical and non-numerical information of the flight. Jeppesen charts and maps provide visual and spatial cues that help them to remember flight operations. And the small note pad is sometimes used to record tips on flying technique obtained from other pilots. These may help him become a more skilled pilot.

CONCLUSION

Our ethnographic study on the work in the flight deck reveals several significant characteristics of the routine interactions among crews with paperwork. We suggest that these practices have a range of implications for the design of computer-based media to support pilots as they work in collaboration with the elements of the social and material world [10, 14, 15].

As is the case for knowledge workers in their offices, pilots use paperwork throughout the working day and beyond. The special characteristics of the flight deck also make it different from most other settings. The complex, high-stakes, high-tempo nature of the pilots' work requires careful planning of information access and the management of attention. The fact that shared understandings are essential to safe flight means that whatever the representations are, they must not only be available to both pilots, but available to the pilots *jointly* in

interaction with one another. While engaging in a briefing preceding a high-workload maneuver such as a takeoff, pilots want to locate themselves bodily in an environment that is rich in tangible representations of the parameters relevant to upcoming events. Currently they do this by reading across many disparate documents and displays. A better understanding of how this is done could contribute to the next generation of display design.

There is no doubt that the EFBs and ECLs and other computer-based tools can enhance the efficiency of certain flight deck procedures. But paper is not just an independent resource that somehow has continued to survive despite attempts to remove it, but rather is an integral feature of using new technologies [18]. It may be possible to eliminate some classes of paper from the commercial airline flight deck, but it is probably neither possible nor desirable to attempt to eliminate all paper from the flight deck. Properly designed interfaces to digital media can provide enhanced functionality for information access, the management of attention, control of depth of processing and the negotiation of shared understandings. How digital media might participate in the establishment and maintenance of social relations and personal identity is less obvious, but it is certainly possible. The challenge for design of the flight decks of the future will be to imagine not just tasks, but whole activity systems that integrate enhanced functionality with practices that are meaningful to pilots and that satisfy their social as well as their information processing needs.

ACKNOWLEDGEMENTS

This research was funded and under contract from the Boeing Commercial Airplanes Group.

REFERENCES

1. Allen, D. (2003). Electronic Flight Bag. *Aero* 23. Vol. 23, pp. 6-27.
2. Chandra, D. (2002). Human factors evaluation of Electronic Flight Bags. In Proc. of *HCI-Aero*, pp. 69-73.
3. Chandra, D. (2003). A tool for structured evaluation of electronic flight bag usability. In Proc. of *DASC 03*. Vol.2, pp.13.E.1- 13.E.2.8.
4. Chandra, D., Yeh, M. and Riley, V. (2004). Designing and testing a tool for evaluating electronic flight bags. In Proc. of *HCI-Aero 2004*.
5. Clark, H. H. (1992). *Arenas of Language Use*. Chicago, IL: University of Chicago Press.
6. Dourish, P. (2006). Implications for Design. In Proc. of *CHI '06*, pp.541-550.
7. Flight Safety Foundation. (2005). 'Paperless flight deck' promises advances in safety, efficiency. *Avionics News*. pp.30-37.
8. Hartswood, M., Procter, R., Rouncefield, M., and Slack, R. (2003). Making a case in medical work: Implications for electronic medical record. *Computer Supported Cooperative Work*. Vol. 12, No. 3, pp.241-266.
9. Heath, C. and Luff, P. (1996). Documents and professional practice: 'Bad' organizational reasons for 'good' clinical records. In Proc. of *CSCW '96*, pp.354-362.
10. Hollan, J., Hutchins, E., and Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer Interaction. *ACM Transactions on Computer-Human Interaction*. Vol. 7, No. 2, pp. 174-196.
11. Hughes, J., King, V. Rodden, T., and Andersen, H. (1994). Moving out of the control room: Ethnography in system design. In Proc. of *CSCW '94*, pp.429-439.
12. Hughes, J., King, V., Rodden, T., Andersen, H. (1995). The role of ethnography in interactive systems design. *Interactions*. Vol. 2, No. 2, pp. 56-65.
13. Hutchins, E. (1998). Metaphors for interface design. In M.M. Taylor, F. Neel, and D.G. Bouwhuis (Eds.) *The Structure of Multimodal Dialogue*. Amsterdam: North Holland, pp.11-28.
14. Hutchins, E. (1995). *Cognition in the Wild*. Cambridge, MA: MIT Press.
15. Hutchins, E. (1995). How a flight deck remembers its speeds. *Cognitive Science*. Vol. 19, pp.265-288.
16. Jouanneaux, M. (1999). *Le Pilote est Toujours Devant: Reconnaissance de l'activite du Pilote de Ligne*. Toulouse: Editions Octares.
17. Luff, P., Heath, C., and Greatbatch, D. (1992). Tasks in interaction: Paper and screen based documentation in collaborative activity. In Proc. of *CSCW '92*, pp.163-170.
18. Luff, P., Heath, C., Norrie, M., Signer, B., and Hersman, P. (2004). Only touching the surface: Creating affinities between digital content and paper. In Proc. of *CSCW '04*, pp.523-532.
19. Mackay, W. E. (2000). Is Paper Safer?: The role of paper flight strips in air traffic control, *ACM Transactions on Computer-Human Interaction*, Vol.6, No. 4, pp.311-340.
20. O'Hara, K. and Sellen, A. (1997). A comparison of reading paper and on-line documents. In Proc. of *CHI '97*, pp.335-342.
21. Rouncefield, M. Hughes, J, and Roden, T. (1994). Working with constant interruption: CSCW and the small office. In Proc. of *CSCW '94*, pp.275-286.
22. Schilit, B. N., Golvchinsky, G., Price, M. N. (1998). Beyond paper: Supporting active reading with free form digital ink annotations. In Proc. of *CHI '98*, pp.249-256.
23. Sellen A. and Harper R. (1997). Paper as an analytic resource for the design of new technologies. In Proc. of *CHI '97*, pp.319-326.
24. Sellen A. and Harper R. (2001). *The Myth of the Paperless Office*. Cambridge, MA: The MIT Press.
25. Shamo, M. K. What is an electronic flight bag and what is it doing in my flight deck? (2000). In Proc. of *HCI-Aero 2000*, pp.60-70.