The Uses of Paper in Commercial Airline Flight Operations

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ABSTRACT
Designers of commercial aviation flight decks have recently begun to consider ways to reduce or eliminate the use of paper documents in flight operations. Using ethnographic methods we describe the cognitive functions served by the paper-use practices of pilots. The special characteristics of flight deck work give a distinctive quality to pilots' paper-use practices. The complex high-stakes high-tempo nature of pilots' work makes shared understandings essential to safe flight. This means that representation of flight critical information must not only be available to both pilots, but available to the pilots jointly in interaction with one another. The cross-cultural component of our work shows how language and culture color all of the pilots' practices and how interaction with paper objects allows actors to build social identities and social relations.

Categories and Subject Descriptors
H.1.2 [**Information Systems**]: User/Machine Systems

General Terms
Design, Human Factors.

Keywords
Paper-use practices, commercial airline flight deck, ethnography, distributed cognition, workplace design.

1. INTRODUCTION
A number of researchers in Computer Supported Cooperative Work (CSCW) and Human Computer Interaction (HCI) have documented the use of paper documents in various kinds of work settings, including hospitals [4, 6, 17], a railway control room [5, 17], architect's office [17], small office [21], financial institution [23], air traffic controller [10, 19], police, chocolate manufacture, and so on [24]. These studies have highlighted the advantages and affordances of paper such as resilience in collaborative settings [4, 17], flexibility in spatial layout [19, 22, 23] ease of manipulation [20, 23], possibility of direct marking [20, 22, 23], awareness [5, 19,] or 'at a glance' nature [22, 23], physicality [23], ease of planning and organization strategies and recording key decisions in hectic work places [19], embodiment of activity histories and memories [10], and so on.

Paper plays many of the same roles in the commercial airline flight deck as have been observed in these other work settings. Furthermore, as is the case with many other modern work settings, pressures exist to eliminate or reduce the use of 'old-fashioned' paper in the airline flight deck [1, 3], and concerns about its elimination have been voiced [25].

The airline flight deck is different in some important ways from other settings.

First, flying is a high-stakes activity. Crews must therefore coordinate closely with each other and with documents that guide their actions. Even when two pilots are engaged in seemingly distinct activities, they employ various devices to keep each other peripherally aware of their activities.[5, 19]. Second, airplanes move rapidly between geographic regions and weather systems. This means that relevant information about the airplane's surroundings can change quickly. Airplanes also move quickly among operational contexts. Each phase of flight (taxi, takeoff, departure, climb, cruise, descent, approach, landing, and taxi) requires different kinds of information. Third, the flight deck is more isolated from the workspaces that form its operational context (air traffic control, company, other aircraft) than is typically the case for terrestrial offices. The modern flight deck is connected to these other activities via a unique combination of voice and data radio links. But, once in flight, it is not possible to call for extra workers, nor to replace or repair broken equipment. Whatever problems arise on the flight deck, they must be dealt with using the human and material resources that are already aboard. Fourth, the sheer weight of paper documents is a major concern in the flight deck because every extra gram of weight carried in an airplane must be paid for in extra fuel consumption [1]. Fifth, the flight deck is physically a small space, and pilots are less mobile in their workstations than the typical office worker is. Display space is, therefore, at a premium. Finally, activity in the airline flight deck takes place under severe temporal constraints. It is not always simply a problem of working quickly, rather the problem is to match the pace of work to the pace of events. On the ground, there are pressures to work quickly to maintain position in the flow of ground operations and to stay on schedule. Once in the air, an airplane must continue moving. As a result, opportunities for delaying activities are

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Table 1: Summary of research subjects.

Field Sites	Revenue Flights		FSS Trainings	
	Number of flights	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 pilots (3 captains and 4 first officers)
North America (Japanese airlines)	---	---	37 hours (26 hours of simulator and 11 hours of brief/debrief)	3 pilots (3 captains)
New Zealand	21	14 pilots	4 hours (2 hours of simulator and 2 hours of brief/debrief)	2 pilots (1 captain and 1 first officer)

extremely limited, and information availability must be planned in advance.

These characteristics of the airline flight deck socio-technical system create a unique cognitive ecology [13, 7]. The observed patterns of paper use can be seen as adaptations to the information management challenges that arise in the interactions of existing technology with these workplace characteristics.

We use the distributed cognition framework [7, 12, 13, 14, 15] to characterize and analyze the nature of these adaptations. This approach explicitly acknowledges that cognitive processes typically emerge from interactions among internal (mental) and external (cultural) resources. For example, an examination of memory processes in a flight deck shows that memory involves a rich interaction between internal processes, the manipulation of objects, and the traffic in representations among the pilots. Our study involves additional complications because we are looking at paper usage in the flight deck across boundaries of language and culture. Pilots make use of their prior experience, including elements that are typically associated with national and institutional culture, in the process of developing or entering a culture of flying [14]. Our preliminary data indicate that paper plays different roles in different cultural contexts of airline operations.

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). The 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 [11]. There is no doubt that ECLs, EFBs, and other similar systems will play an important role in flight decks of the future. Manufacturers and operators are already exploring the space of possibilities for this sort of technology. This is an opportune moment to contribute to this development by providing an analysis of actual, everyday paper-based work practices in the global airline flight deck. To our knowledge, however, few research findings based on ethnographic observation [8, 9] describing how pilots use paper in flight operations have been reported. We believe that a careful documentation of pilots’ actual paper-use practices in the flight deck should inform decisions about what should remain on paper, and what could be migrated to digital devices [6].

We are now in the early stages of a worldwide investigation of the roles of language and culture in commercial airline flight deck operations [14, 15]. 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.

2. RESEARCH METHODS

We conducted a series of field research studies at airlines in Japan and New Zealand in 2005. In the field research studies, we occupy the observer’s seat in the flight deck and observe pilots flying in revenue service. We videotape pilots flying in full-motion simulators, and interview pilots about their work practices. Our flight observations took place in the Boeing 777, 747-400 and 737-300 aircraft. The simulator sessions were in the Boeing 777.

We have assembled a distinctive research team that includes technical pilots, flight deck human factors specialists, a cognitive anthropologist and a native Japanese HCI researcher. 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).

2.1 Revenue Flight

We shadowed the appointed pilots through their work day. We typically met with pilots at the operations office at the airport, where they check weather and flight plan information. 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 operations 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 which is 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. In every airline flight deck, there is at least one observer’s seat, located just behind the pilots’ seats. Although videotaping was prohibited, from these seats, 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 crews.

2.2 High Fidelity Simulator Flight

The full-flight simulator provides pilots with a precisely replicated flight deck that behaves like a real airplane. Visual, aural, haptic, and some g-force stimuli are simulated with high fidelity. This allows pilots to fly the aircraft simulator as they would fly the real airplane in line operations, except, of course, that in the simulator they will encounter emergencies that one hopes they will never face in revenue flight. In the simulator, we videotaped flight deck activity using two cameras simultaneously. One camera was placed behind the pilots and provided an over-the-shoulder view that included the instrument panel. The other camera was a wide angle lens mounted low on the instrument panel and provided a view of the pilots' faces and hands. Lapel microphones provided audio signals that were recorded in stereo on the audio track of the first video camera.

For the in-house training conducted at Japanese airlines, pilots and instructors in the training were all Japanese, and training was conducted in Japanese. We also participated in 37 hours of transition training for three Japanese captains at a training center in North America. Since the instructor in this training was a native English speaker, the training was conducted in English. The pilots of our airline in New Zealand are native English speakers and all training observed there was conducted in English.

3. PAPER USE IN THE FLIGHT DECK

3.1 What Kind of Papers and Where?

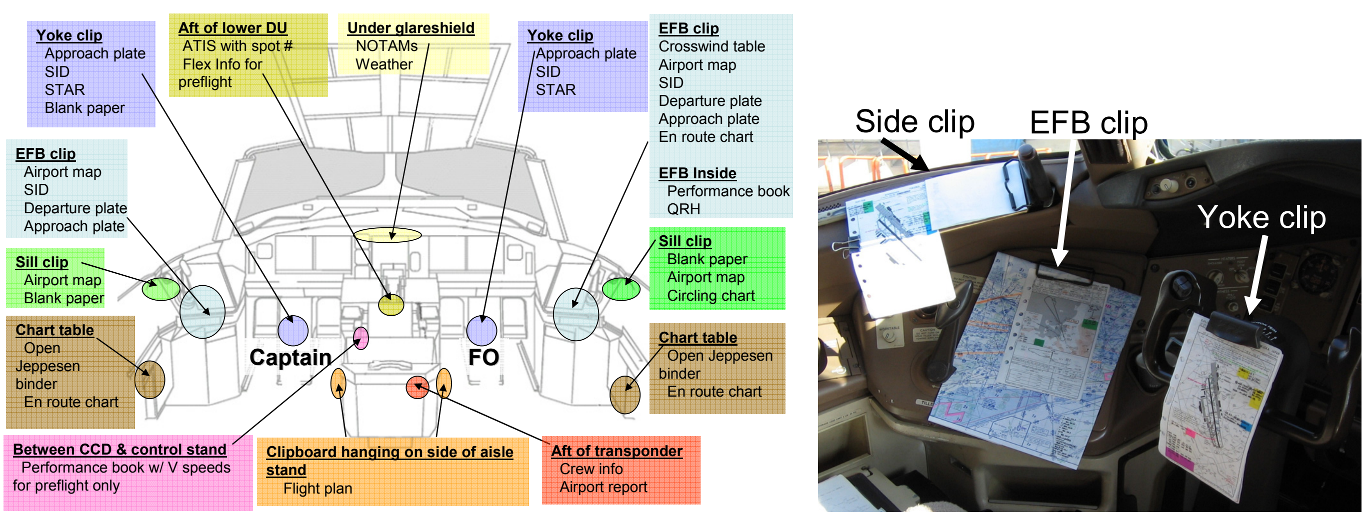
3.1.1 Dispatch Papers and Personal Documents

Several pages of paper are brought into the flight deck at the beginning of each flight. These are provided by company dispatch and are carried on board by the pilots, or are given to the pilots by maintenance personnel prior to pushback. These papers include 'crew information', 'dispatch release', 'passenger list', 'airport information', 'special load', and 'NOTAM' (Notice to Airman). The crew information document includes the names, employment information, and duty stations of flight and cabin crews. The dispatch release document consists of about 5-6 pages. It contains company clearance, pilot in command, airplane identification, summary flight plan, navigation log, weather briefing, and allowable takeoff/landing weights. The passenger list indicates the names and seats of special passengers on board the airplane, such as those who need medical support. Airport information lists airport weather including runway conditions, and supports for planning takeoffs and landings. NOTAMs describe any circumstances that may affect flight operations in the area. Pilots review this information before leaving the operations office. They generally discuss this information with each other and may also discuss it with a dispatcher, if one is provided by the airline.

Pilots also carry their own heavy flight bags on board. Each flight bag contains aircraft operating manuals, airway route manuals, and Quick Reference Handbooks (QRH). It is unusual to refer to the aircraft operating manual in flight. However, pilots access charts in the route manual on every flight. This thick binder includes aeronautical charts (so called Jeppesen charts) such as airport maps, and approach and departure charts. Pilots remove necessary charts and maps from the binder according to the flight context. The QRH contains performance information and a set of 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. There is a 'Handy Performance Book' separate from the QRH that contains performance tables and in-flight performance data.

3.1.2 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 requests and 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 information includes weight and balance of the aircraft, take-off runway, flight weather,



a) Spatial layout of papers in the flight deck during the flight **b) Paper setup at the captain's seat in approach-taxi phase**

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

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 things including the 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.

3.1.3 Spatial Layout of Papers in the Flight Deck

Papers are distributed throughout the flight deck during the flight. Figure 1a) illustrates the observed locations of various papers in a Boeing 777 during a short flight. The captain sits in the left seat and the first officer sits in the right seat.

Pilots usually place airport maps, standard instrument departure charts (SID), and standard arrival charts (STAR) on a yoke clip, or where an EFB (Electronic Flight Bag) could be installed (EFB clip), or on a side-window clip. An en route chart (low altitude flight plan map) is located either on the EFB clip or on the chart table. The Jeppesen binder opened to the next necessary chart and personal notes created by pilots are placed on a chart table. The scratch pad is provided by the company and is located on the side window clip. Two pilots usually have the same charts available and organized similarly on each side. This redundant arrangement of information sources supports coordinated interpretation and action by the pilots. In the first officer's side compartment where the EFB will be in the future, additional copies of the quick reference handbook and the handy performance book are stowed by the company.

Pilots rearrange the charts and airport maps according to the flight context. For example, prior to takeoff, 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 organize their charts with the arrival procedure lying on the flight bag, airport map on the side window clip, en route chart below the airport map, and approach plate on the yoke clip (See Figure 1 b)).

At some airlines, dispatch release documents were put on a clipboard and hung on either side of the aisle stand in the 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 ACARS brings many kinds of information into the flight deck. Since there is only one screen for the display of information received via ACARS, the printer acts as a sort of

[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.

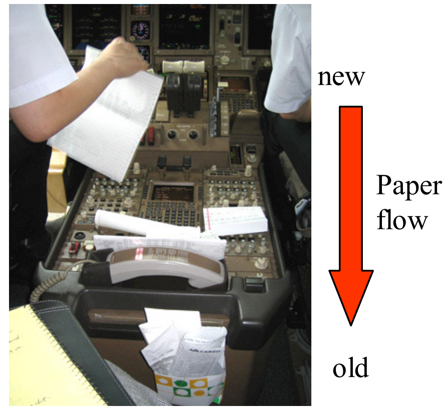


Figure 2: Old papers are moved out of work space, but still within pilots' arms' reach.

display multiplier by making it possible to print and display many ACARS messages simultaneously.

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. Pilots handwrite the arrival gate number on the arrival airport information ACARS printout,. When pilots replace an ACARS printout with an updated version, the old one is archived by moving it aft on the aisle stand, or a small pocket on the side console to archive them. One pilot created a paper archive box by adapting a cardboard lunch box (See figure 2). Since pilots know that on some occasions they may need to refer to old information, they don't dispose of these papers until they have landed.

3.2 How Are Papers Used?

Throughout the flight, paper plays important roles in crew coordination, message confirmation, note-taking, and information affordance. In this section, we will use descriptions of work practices to highlight the cognitive functions in which paper is involved.

3.2.1 Crew Coordination

Each flight begins in the operations office. Here pilots receive and review the dispatch papers for the flight. In 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 a 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 talk, gesture, and 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 micro-rituals that express the social organization of the crew while handling 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 has 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 neatly along the aisles and behind seats two rows back. The captain holds dispatch papers and cabin crews bring their personal small memo pads and pens. 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 need medical assistance. Members of the cabin crew nod to exhibit their comprehension to the captain and take notes during the briefing.

3.2.2 Paper Supported Data Entry

In the flight deck, coordination between pilots is one of the most important aspects of flight operations, and here too paper plays a role. During the pre-flight phase, pilots enter data into the Flight Management Computer (FMC) via a Control and Display Unit (CDU). Pilots retrieve data for entry from many paper documents. After one pilot enters the route of flight, both pilots then do a careful cross-check of the route. For example, the captain displays the route on his CDU while the first officer reads the route waypoints one at a time from the navigation log in the dispatch 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 dispatch papers. Performance data (final aircraft weight and takeoff thrust settings) are typically entered into the FMC after being requested via ACARS and printed out. 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, the captain called out "348900" while the first officer enters 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.

Table 2: Takeoff briefing conducted in one carrier in Japan.

	Speaker	Translated Speech	Gesture
1.	PF:	*Then, Let's do* Takeoff briefing.	PF who is sitting on the right side picks up a dispatch paper from the center console with his left hand.
2.	PM:	*OK.*	PM who is sitting on the left side pushes and views CDU on his side.
3.	PF: {PM}:	*Let's see.* Weather information, **Quebec, *roger*. *Well*, using runway three-four right**. {*Yes*}. *(We have) already checked* the performance *before*. *Uhhh*, *one-five-one-one*, **braking action, poor**. *Well,* ***five hundred and ninety-eight thousand*** **pounds**. {*Yes*}. *So*, *(it) is almost the same as* plan weight*. Ah*... fuel *is* minus *one-hundred, though*, {*Yes*}, *it is* **recovered** *now*, *and* ***about twenty-two thousands***, {*Yes*}, order fuel *is the same*. {*Yes*}. *Well*, performance, check. *Uhh*, **TOKYO HANEDA** *is, uhh*.., above take-off, *ahh,* below landing minimum {*Yes*}. NARITA *is* [2 seconds] *ahh taken as* a takeoff alternate {*Yes*}.	PF reads the dispatch paper, "**Quebec, *roger*. *Well*, using runway three-four right,**" holding with his left hand. PM looks the PF's paperwork out of the corner of his eyes. PM pushes CDU button on his side when PF says "**using runway three-four right**." PF also pushes CDU button on his side after he says "***five hundred and ninety-eight thousand*** **pounds**." When PF explains "**recovered**" of the fuel amount, he points at the center display which indicates fuel amount with his left index finger, and then reads aloud the fuel amount "***about twenty-two thousands***" on the display. PF moves the dispatch paper with his left hand to place it in between the pilots. He points the center display with his left index finger when he talks about the fuel amount.
4.	PF: {PM}:	*Ahh, wind is* **two hundred fifty** *degree* **ten** knots, *isn't it?* {*Yes*}. ***Two-nine-eight-nine***, set. *Well, no* NOTAM. *Ahh.., from number* ***seven hundred and one***, *ahh*, **runway three-four right** full length. {*Yes*}. Flap *will get down after going to the* end *of the* runway, {*Roger*} *uhh* check control, *well*, *do a* static takeoff. *Let's see… About* RTO. *At* 'before eighty', *(with*) any malfunction, *ah.., (the takeoff will be)* rejected*. Ahh, as for* 'eighty to V one', reject *(the take-off) will be held at* engine fail *and also* fire. {*Yes*}. *And then, when I would judge that something such as* master warning *which cause critical troubles in continuation of departure, (we are) going* reject *(the takeoff)*. {*Yes*}.	After saying "***Two-nine-eight-nine***, set", PF places the document back to the center console. When he says "*from number* ***seven hundred and one***," he sees the airport map which is placed on a side clip on his right and touches the runway on the chart with his right hand. He sees to PM's face and airport map one after another several times. PM also sees his airport map on his left and also PF's face alternately. For listing the RTO condition, PF uses his memory. He uses left hand to counting items on his fingers. PM sees PF's fingers.
5.	PF: {PM}:	*Regarding* 'after V one', *(we will)* follow reference procedure, *and uhh.., then (do)* **right turn** *at three-hundred* feet. *Ahh…, (we) will be using o-pai.{Roger}*	PF turns the map right on and views the airport map on his right again. When he says "**right turn**", he draws right turn with his left hand on the map. PM sees the PF and when he knows PF sees the airport map, he also sees his map on his left.

Note: Numbers in brackets [ ] represent silent seconds, braces { } indicate the other speaker's remarks, and parenthesis ( ) indicate the addition of features that are usually omitted in the original language. **Bold font** letters denote information presented on displays or papers in the pilots' visual field, *italic letters* represent remarks spoken in the original language (Japanese), and standard letters represented in English in the original speech.

Pilots engage in a formal briefing activity before takeoffs and approaches. The briefing practice is an acknowledgement of the special characteristics of these maneuvers; they are complex, high-stakes, high-tempo, multi-operator events. Table 2 is a transcript of a takeoff briefing conducted in a simulator training session. In the table, speech is translated into English from the original Japanese language which the pilots used. The original speech in this briefing was a complex mix of Japanese, English, and aviation technical terms. While conducting this takeoff briefing, both pilots refer to and gesture toward dispatch papers including a chart of the engine-failure reference procedure for Runway 34R of HANEDA airport, a HANEDA airport map, airport weather report, and information on various flight deck displays.

Here, pilots use multiple representations to coordinate with each other: speech in Japanese, speech in English technical terms, facial expression and eye contact which support common ground understandings [2] between the pilots, displays (CDU and center display which shows fuel amount), dispatch papers, and airport maps. Note that the PM responds saying, "Yes." to each important utterance produced by the PF. Since the PM also looks at the dispatch paper which the PF reads aloud, the PF moves the paper toward the PM's line of sight. When the PF reads data from his airport map, the PM looks at his own airport map to maintain coordination of visual and auditory experience.

3.2.3 Cross-Reference of Paper Work

Pilots must confirm the accuracy of certain types of information through multiple data sources and representations. For example, on takeoff, pilots 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 (takeoff speeds) by comparing three sources of information. 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 operations manual. One senior Japanese captain commented,

> The problem with the FMC is that it assumes a dry runway. If the runway is wet or icy or contaminated, the V-speeds computed by the FMC may not be correct. In that case, I would have to go to the flight operations manual to find the corrections to be applied to the speeds depending on the nature of the contamination of the runway.

At one airport where the runway was wet, a crew compared the FMC to dispatch V-speeds. The captain instructed the first officer to get out the flight operations 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). Pilots use printed performance tables to look up the values that are to be entered in the spaces in the PTOC form (See Figure 3). 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).

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: Cross-reference of paper work at the gate.

Figure 1 b) 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. During an approach, pilots 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. 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.

3.2.4 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.

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 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.

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

3.2.5 Document Personalization

Many 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. 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 also help pilots to find particular charts in the Jeppesen binder which contains hundreds of similar looking pages. Colorful sticky notes are used for temporary messages and/or very important messages which should catch pilot's eyes very easily (See Figure 1 b)).

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 text, 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 work. They bring all paperwork created in the flight back home and run through the events of the day.

> 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]

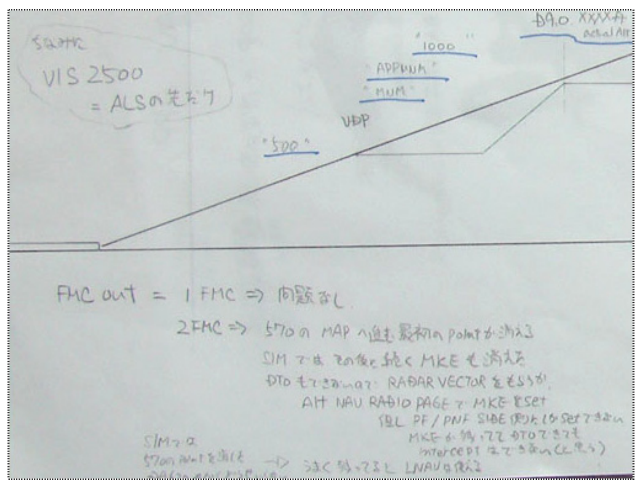


Figure 5: Document customization using color and pilot's native language.

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 Japanese. Here annotation serves both to control the allocation of attention to the document and to increase the depth of processing of the information on the document.

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 this frequently needed information.

4. DISCUSSION

4.1 Discussion on Paper Use

The features and functions of paper documents that have been documented in other settings also play potent roles in the flight deck. Papers are also effectively used with other representations (such as radio communication and display units) according to the nature of information and contexts [5, 10, 19].

Firstly, the *flexibility* of paper enables pilots to cross-reference and coordinate multiple representations. Pilots use binder clips and switches, that were *not* designed as paper holders, to array papers around themselves efficiently. 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 must refer to several dispatch documents and an ACARS printout to extract numerical information. Pilots confirm the consistency of information in multiple independent data sources in collaboration with each other before activating that information in the FMC.

Pilots spread out papers and keep active or ‘hot’ documents [24] in their field of vision. The yoke clip, side window clip, and EFB clip are easily seen and ready-at-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, and make information immediately available, accessible, and shareable.

When pilots prepare for a takeoff or an approach, they need to make decisions and imagine the trajectory ahead of them. 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 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 condition. Here, pilots coordinate static representations that are printed on papers with the current conditions as depicted in multimodal representations. The event-driven nature of flying requires pre-planning of information access. The heavy demands on pilot attention during takeoffs and approaches mean that in these phases of flight, information search costs must be keep to a minimum. When 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. Even the pilot flying (PF), who is supposed to listen to the read-out of the pilot monitoring (PM) and to execute the actions, keeps his eyes on the checklist texts. Since paper is flexible to handle, the PM can lean toward his co-pilot and place the checklist in his line of sight. This action facilitates the establishment of common-ground understandings between pilots. Since the PM can position a paper checklist to accommodate the visual needs of the PF, the PF may not need to turn his eyes as far away from relevant equipment or the windscreen as would be required by a fixed location electronic display.

Secondly, 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 paper documents between pilots provides a means for enacting the social relationship between them. In Japan, when an artifact is handed from a lower social status person (the first officer in this case) to a 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 the 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 in some cultures to reconfirm 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 held in the business-class 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 expected flow of information among the crew members.

Thirdly, the *customizability* of paper supports pilots’ cognitive activities. Many pilots 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 helps to establish and maintain familiarity with airports and routes. This effect appears to be especially important 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 comprehension of the procedures. They also create home-made charts and performance tables and file them in their route manual. These personal notes are written in an effective combination of their native language and English technical terms.

Annotation is not always directed to oneself. Highlighting and hand written notes are applied to dispatch paperwork by dispatchers for the benefit of pilots. The appropriate application of annotation provides the dispatcher a way to demonstrate professional competence. Paper therefore also plays a role in the establishment of identity of the user.

The customizability of paper also allows pilots to take notes during the flight. Pilots (especially the PM) often take notes while communicating with air traffic control (ATC). They write down flight number, runway number, taxiway routes, arrival gate number, actual arrival time, and so on. Handwritten notes are used as an external memory and enhance information flow between pilots, among pilots and cabin crew, and between pilots and ATC.

Finally, because of their *portability*, paper documents can maintain the continuity of pilots' experience. The dispatch papers link 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 timing of flight contexts and maneuvers which he or his co-pilot performed. Dispatch papers with the pilot's own handwritten annotations give him accurate numerical and non-numerical information of the flight. Jeppesen charts and maps provide visual and spatial cues that help the pilot to remember flight operations. And the small note pad is sometimes used to record tips on flying technique obtained from the other pilot. These may help him become a more skilful pilot.

4.2 Design Issues

The target of design activity should be the cognitive functions performed in the flight deck. A focus on replacing the current devices (flight bag, checklist, e.g.) is likely to misfire because the way functions are partitioned among devices depends on a complex history of interactions among work practices and device affordances [19]. There is no good reason to expect that functions should be partitioned in the same way with future technologies. For example, the traditional flight bag functions mainly as a library of documents, while current versions of electronic flight bag are most valued for their support of performance calculations.

Consider the cognitive function of managing the allocation of attention. The management of the allocation of attention among documents is supported by the placement of documents around the flight deck, while the management of the allocation of attention within documents is supported by highlighting and annotation. Both strategies can reduce the costs of information access. If information is represented on a portable display, a pilot may affect the partner's attention by moving a display into the partner's line of sight. Designers could approach this problem by providing spatial positioning or annotation facilities in new document display technologies, or they might imagine other mechanisms that crews could use to manage the allocation of attention.

Both memory and forgetting are important functions in the flight deck. With paper-based media the placement of documents plays a role again here. Documents containing information to be remembered are kept forward and or near the centerline of the flight deck, while those bearing information to be forgotten (no longer active) are moved aft or outboard. We observed many specialized paper folding techniques that permit paper displays to be located in a surprising variety of locations. Coupled with the display-multiplying function of the printer, pilots are able to make their environment rich in information. These practices fit the affordances of paper technology and exploit very robust mappings of perceptual (position) to conceptual (currency) cues, but the same functions could be supported in other ways in other representational media.

In order to create robust situation awareness, pilots must integrate information from multiple sources and they must have joint access to those sources in order to make their situation awareness [5, 19] part of the common ground of their interaction. This will always be true in the flight deck. But the means for arranging information sources and for integrating the information on them may be very different in the flight deck of the future. 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.

As they are used in current work practices, paper objects are also involved in a number of aspects of the job that are difficult to articulate, but that may be quite important. Paper objects provide a context for the performance of micro-social rituals in which the social order is enacted and confirmed. They appear to provide means for actors to assert their identity as competent practitioners in various roles. These are examples of what Mackay [19] refers to as "intangible" factors in paper use. Such factors are often overlooked by designers, and when overlooked, they often become sources of resistance to change. These factors are especially easy to miss in cross-cultural conditions where the meaning-making of the cultural others often goes unnoticed.

5. CONCLUSION

This paper is a part of the series of studies on flight deck culture in worldwide airlines. Our ethnographic study of the commercial airline flight deck shows how the paper-use practices of pilots serve a set of important cognitive functions. 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 [7, 12, 13]

Our research shows that pilots use paper in ways that have been discussed by previous CSCW and HCI researches studying other workplaces, such as a knowledge worker's office. Pilots use paperwork from the beginning to the end of their working day and beyond. Their practices implicitly distinguish hot, warm, and cold documents according to the flight context. They array and refer across the multiple paper and computer displays, jointly review papers with a co-pilot in coordination, take notes, and bring paperwork home to review the events of the day.

But 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 limited extent of non-window surface space combined with the immobility of the pilots in the flight deck constrains the viable options for arrangement of display surfaces. 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. The cost of carrying unnecessary weight puts pressures on the system to eliminate some classes of paper – charts and manuals especially.

The cross-cultural component of our work shows how language and culture influence all of the pilots' practices and how interaction with paper objects allows actors to build social identities and social relations.

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 simply a vestige of an old world that somehow has continued to survive despite attempts to remove it. We predict that paper will be an integral part of using new technologies [18]. Effective design solutions to the challenges of reducing the amount of paper in the flight deck require better understanding of the functions served by paper and of the mechanisms that can implement those functions in other media.

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7. REFERENCES

[1] Allen, D. Electronic Flight Bag. *Aero 23*. 23, 2003, 6-27.

[2] Clark, H. H. *Arenas of Language Use*. Chicago, IL: University of Chicago Press, 1992.

[3] Flight Safety Foundation. 'Paperless flight deck' promises advances in safety, efficiency. *Avionics News*. September 2005, 30-37.

[4] Hartswood, M., Procter, R., Rouncefield, M., and Slack, R. Making a case in medical work: Implications for electronic medical record. *Computer Supported Cooperative Work*. 12 (3), 2003, 241-266.

[5] Heath, C. and Luff, P. Collaborative activity and technological design: Task coordination in London underground control rooms. In *Proc. of ECSCW1991*, 65-80.

[6] Heath, C. and Luff, P. Documents and professional practice: 'Bad' organizational reasons for 'good' clinical records. In *Proc. of CSCW 1996.* ACM, 354-362.

[7] Hollan, J., Hutchins, E., and Kirsh, D. Distributed cognition: Toward a new foundation for human-computer Interaction. *ACM Transactions on Computer-Human Interaction*. 7(2), 2000, 174-196.

[8] Hughes, J., King, V. Rodden, T., and Andersen, H. Moving out of the control room: Ethnography in system design. In *Proc. of CSCW 1994*. ACM, 429-439.

[9] Hughes, J., King, V., Rodden, T., and Andersen, H. The role of ethnography in interactive systems design. *Interactions*. 2(2), 1995, 56-65.

[10] Hughes, J., Randall, D., and Shapiro, D. Faltering from ethnography to design. In *Proc. of CSCW 1992.* ACM, 115-122.

[11] Hutchins, E. Metaphors for interface design. In M.M. Taylor, F. Neel, and D.G. Bouwhuis (Eds.) *The structure of multimodal dialogue*. Amsterdam: North Holland, 1988, 11-28.

[12] Hutchins, E. *Cognition in the wild*. Cambridge, MA: MIT Press, 1995.

[13] Hutchins, E. How a flight deck remembers its speeds. *Cognitive Science*. 19, 1995, 265-288.

[14] Hutchins, E., Holder, B.E., and Perez, R.A. *Culture and flight deck operations*. Prepared for the Boeing Company, 2002. (unpublished)

[15] Hutchins, E., Nomura, S., and Barbara Holder. The ecology of language practices in worldwide airline flight deck operations. In *Proc. of CogSci2006*. Cognitive Science Society, 363-368.

[16] Jouanneaux, M. *Le pilote est toujours devant: reconnaissance de l'activite du pilote de ligne*. Toulouse: Editions Octares, 1999.

[17] Luff, P., Heath, C., and Greatbatch, D. Tasks in interaction: Paper and screen based documentation in collaborative activity. In *Proc. of CSCW 1992.* ACM, 163-170.

[18] Luff, P., Heath, C.,Norrie, M., Signer, B., and Hersman, P. Only touching the surface: Creating affinities between digital content and paper. In *Proc. of CSCW 2004.* ACM, 523-532.

[19] Mackay, W. E. Is Paper Safer?: The role of paper flight strips in air traffic control, *ACM Transactions on Computer-Human Interaction*, 6(4), 2000, 311-340.

[20] O'Hara, K. and Sellen, A. A comparison of reading paper and on-line documents. In *Proc. of CHI 1997*. ACM, 335-342.

[21] Rouncefield, M. Hughes, J, and Roden, T. Working with constant interruption: CSCW and the small office. In *Proc. of CSCW1994.* ACM, 275-286.

[22] Schilit, B. N., Golvchinsky, G., Price, M. N. Beyond Paper: Supporting active reading with free form digital ink annotations. In *Proc. of CHI 1998.* ACM, 249-256.

[23] Sellen A. and Harper R. Paper as an analytic resource for the design of new technologies. In *Proc. of CHI 1997.* ACM Press, 319-326.

[24] Sellen A. and Harper R. *The Myth of the Paperless Office*. Cambridge, MA: The MIT Press, 2001.

[25] Shamo, M. K. What is an electronic flight bag and what is it doing in my flight deck? In *Proc. of HCI-Aero 2000*, 60-70.