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ORIGINAL ARTICLE

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Human computer interaction methods for electronic flight bag envisionment and design

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Abstract This paper reports on the application of a range of human computer interaction (HCI) methods to the re-design of an electronic flight bag (EFB), as part of a commercial software development project. Specifically, it focusses on the use of participatory design methods, for resolving EFB usability problems. The purpose of this case study is to: (a) Show how participatory design methods can be effectively combined with ethnographic techniques and more formal methods in HCI, for the development of human-friendly EFB systems, (b) Illuminate the specific EFB usability issues encountered in this research and related HCI solutions, (c) Generate an awareness of the challenges faced by HCI practitioners adapting HCI methods to meet commercial project constraints. The HCI methodology outlined in this case study may be of interest to practitioners tasked with process and technology envisionment and/or working with limited resources.

Keywords Electronic flight bag (EFB) · Human computer interaction · Participatory design · Ethnographic research · Prototyping · User testing

1 Introduction

Supplemental flight information (traditionally presented in paper format and carried in the pilot's flight bag) is now being presented in digital format. This digital medium is termed the electronic flight bag (EFB), (Shamo 2000). This new format provides opportunities to exploit information presentation functions not possible with paper, to improve information access and presentation (e.g. de-cluttering information, presenting timely information, pre-populating information).

Electronic flight bag usability is critical to flight safety. Poor usability (inefficient task workflows and/or confusing information displays) can be costly in terms of pilot time/attention and overall workload. Pilots are continuously prioritising and sequencing flight tasks, at different points in flight. For example, to access or make landing calculations, pilots must monitor a range of information displays (e.g. flight management system, situation displays, EFB and so forth) and resources (e.g. navigation charts). Evidently, problems in accessing/making landing calculations will distract pilots from the primary task of flying the aircraft safely, and could result in a loss of situation awareness at a critical point in flight. The accident literature details many accidents where loss of situation awareness and/or poor task management contributes to pilot error.

This paper reports on the application of a range of HCI methods to the re-design of an EFB, as part of a commercial software project. This first section provides an introduction to EFBs and human computer interaction (HCI) methods. Following this, a summary of project objectives and methods is presented. Next, a detailed description of EFB re-design HCI methods (and related limitations) is provided. After this, specific EFB usability issues which arose in user testing and ethnographic research are discussed. The design solutions which emerged in participatory design (PD) activities are then described. The final section focusses on the efficacy of PD methods in terms of the project context and requirements. Forthcoming HCI work is also discussed in relation to certain method limitations. This paper concludes with a proposed methodology for applied HCI research.

2 Background

2.1 Users and tasks

Primarily, EFBs are used by commercial transport pilots for the performance of flight management tasks, both

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during flight and in the aircraft turnaround. Currently, the range of functionality supported includes aircraft performance calculations (e.g. weight and balance calculations, takeoff calculations and landing calculations), weather and situation displays, flight log reporting, aircraft defect reporting, communications and document viewing (checklists, aeronautical charts and maintenance manuals).

Portable EFBs (e.g. EFB software accessed using a laptop, tablet or portable digital assistant) are also used by maintenance engineers for aircraft defect management tasks, in the aircraft turnaround. Maintenance staff can review the technical status of the aircraft (e.g. electronic version of aircraft technical log) and defer or close new or existing aircraft technical defects as required. Engineers can also use EFBs to access relevant maintenance documentation (e.g. aircraft maintenance manuals and illustrated parts catalogues). Advanced EFBs allow engineers to view parts information and/or order parts (e.g. software is integrated with maintenance systems so that engineers can check on the availability of a part and order new parts if required). Further advanced EFBs can support line maintenance tasks (e.g. reporting on daily/weekly checks and non-scheduled maintenance activities).

2.2 Certification of electronic flight bags

The Federal Aviation Administration (FAA 2003) classifies EFB equipment from a self-contained independent (portable) system to a system with multiple data link capabilities that interface with aircraft systems. In cooperation with the FAA, the Joint Aviation Authority (JAA) has provided temporary guidance information regarding EFB certification, airworthiness and operational use (JAA Temporary Guidance Leaflet No. 36). A rule making activity has been initialised based on this, and formal directives are expected in 2006.

There is much similarity between the FAA directives and current JAA proposals. In both cases, Class 1 EFBs are fully portable and not connected to aircraft systems. The JAA specifically refers to these systems as controlled portable electronic devices (PEDs). Class 2 EFBs are portable but connected to the aircraft during normal operations. Such devices can receive data from aircraft avionics systems, but cannot send data to these systems. The FAA requires an administrative control process for the approval of Class 2 devices; the JAA considers Class 2 devices to be controlled PEDs and requires airworthiness approval. Class 3 EFBs are fully installed/integrated systems and are not portable. Both the FAA and JAA require airworthiness certification covering both hardware installation and qualification.

2.3 EFB design challenges

The introduction of EFB systems (transition from paper to electronic tools) will result in flight operations' changes. Process and technology innovation requires careful consideration and presents a number of challenges for EFB vendors. Chief among them is the question of devising suitable HCI methods for EFB envisionment and design. Evidently, methods must facilitate work practice re-engineering/envisionment and the related development of user-friendly work tools.

2.4 Formal methods in human computer interaction

Formal methods in HCI allow for user involvement at specific points in the product development lifecycle (Nielsen 1993; Constantine and Lockwood 1999; Mayhew 1999). Users are first consulted to define system requirements. Usually, this occurs at the beginning of a project and takes the form of structured or semi-structured interviews focussed on understanding and evaluating current work practices and supporting technology (Hackos and Redish 1998). A number of analysis and design steps are then completed by HCI professionals without the participation of end users. First, user requirements are analysed. Typically, this results in specific user and task analysis outputs (e.g. task lists, user profiles, task scenarios and hierarchical task analysis drawings). Design concepts are then modelled (with the help of graphic designers). This involves mapping user tasks and workflows to a set of interface screens with a defined information structure and presentation logic. This process is supported by a wealth of advisory information relating to user interface design. This includes International Organisation for Standardisation (ISO 1995, 1997) user interface design approaches and standards, and usability design principles/heuristics (Nielsen 1993; Preece et al. 2002). Following this, high fidelity prototypes are developed by software developers. Once the prototypes are completed, user workflows and interface features/behaviours are tested, using representative end users (Rubin 1994).

Formal HCI methods have been the subject of much debate in the HCI literature. Specific challenges have come from the fields of ethnography and participatory design. Ethnographers argue that classical HCI methods do not take work practice seriously, failing to address the social aspects of work (Hutchins 1995; Vicente 1999). In particular, they argue that user interviews cannot provide actual insight into real work practices. Participatory design theorists have questioned the separation between design and evaluation in formal methods (Bødker and Burr 2002). Specifically, they have challenged the instructiveness of traditional user and task analysis outputs for design guidance. Also, they argue that user testing provides insufficient information concerning user problems (Bødker and Burr 2002). Further, PD theorists have questioned the usefulness of these methods for the design of sociotechnical systems.

2.5 Participatory design

The field of PD originated in Scandinavia in the early 1970s, in response to union mandates that workers should be involved in the design of new workplace technology. This heralded the introduction of new HCI methodologies, many of which were pioneered in the Utopia Project (Bødker et al. 1985). Central to PD theory is the idea that usability engineers design 'with' end users, as opposed to 'for' them. Accordingly, users are active participants in the design process, and the traditional HCI design team (e.g. usability engineers and graphic designers) is broadened to include end users (workers and worker organisations), stakeholders and domain experts. Crucially, PD theory stresses the relationship between design and evaluation. PD theorists argue that to design effective work tools, design teams must first experience and evaluate future technology and practices (Bannon 1991; Muller 2003). As such, PD techniques (such as the co-creation and evaluation of prototypes and scenario role playing) allow design teams to envision and evaluate future workplace practices and related technologies, without the constraints of current practice.

The PD contention that users must be active participants in the design process, (and related argument that usability engineers should be receptive to user's own ideas and explanatory frameworks) reflects certain underlying phenomenological conceptions of knowledge. Participants are not objects but partners or 'experts' whose ideas are sought (Greenbaum and Kyng 1991). Thus, it is inappropriate for usability engineers to formulate design models in advance of collaboration with end users.

2.6 EFB design and commercial project context

As mentioned previously, one of the key challenges facing EFB designers is identifying suitable HCI design methods (e.g. methods that facilitate work practice re-engineering/envisionment and the related development of user friendly work tools).

This question is intensified if research is conducted as part of a commercial software project. Here, HCI activities are subject to commercial constraints. Both research budgets and project time may be limited (product time to market is critical). Frequently, this necessitates concurrent HCI and software development activities. Also, HCI practitioners and management teams may have different views regarding research rigour and product quality. Management may want problems solved swiftly and not understand the iterative nature of HCI work and/or specific method limitations. In this environment, HCI practitioners must select methods which provide concrete design instruction/feedback so that products are developed both on time and within budget.

The HCI redesign of Aircraft Management Technologies' (AMT) EFB solution was undertaken as part of a commercial software development project. As such, the commercial context determined the scope of HCI research (e.g. time/resources and related choice of methodologies). The next section provides an overview of the project context and HCI methodologies. A detailed description of specific methodologies and their relative strengths and weaknesses is detailed in subsequent sections.

3 Overview of HCI research

3.1 Background

Human computer interaction research commenced prior to the launch of AMT's EFB solution—Flightman^{TM} (version 1), in 2002. At this time, a number of customers were preparing to 'go-live' (deployed on Class 1 devices) and customer trials were underway. As there were no live customers, real-life product usage feedback was unavailable. From a business perspective, product time to market (in terms of an improved version 2 EFB solution) was an important consideration. A small number of airlines were flying with basic EFB solutions (e.g. portable devices displaying electronic manuals and charts with limited interactivity) developed by other EFB vendors/avionics companies.

3.2 About Flightman^{TM} (version 1)

Flightman^{TM} (version 1) featured basic flight management functionality, customised for flight crew and maintenance engineers. Pilot functionality included weight and balance calculations, takeoff/landing calculations, log reporting, defect management and communications. Maintenance functionality included aircraft defect reporting and communications. Hardware included a portable tablet, stylus and detachable keyboard (Fig. 1).

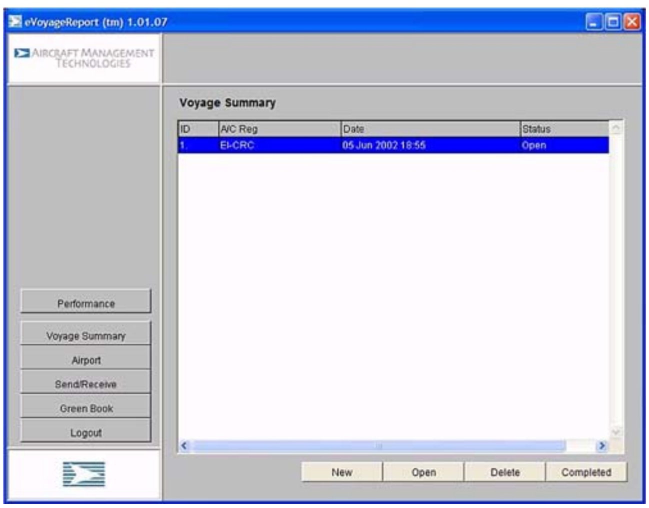

Fig. 1 Opening screen, Flightman^{TM}, version 1

3.3 Research objective

The research objective was practical to produce a user-friendly and ecologically valid model for Flightman^{TM} (version 2), which would allow for the provision of new functionality as the product progressed. Device issues, EFB operational procedures and training requirements were excluded from scope.

3.4 Summary of HCI methods

The first phase of EFB research is complete. To date, research has comprised a range of HCI activities:

- User testing of Flightman^{TM} (version 1)
- Extensive ethnographic interviews and observations
- Production of initial task scenarios and workflow drawings
- Collaborative evaluation of task workflows with end users
- Collaborative production of low fidelity paper prototypes with end users
- Collaborative evaluation and design of low fidelity MS Visio prototypes with end users
- Development of Flightman^{TM} (version 2) high fidelity prototypes
- Informal evaluation of high fidelity prototypes by Volpe

Currently, high fidelity prototypes are being developed. Once complete, the second phase of research will commence (this is outlined at the end of this paper).

4 HCI methods

4.1 User testing

The first step involved user testing Flightman^{TM} (version 1). The purpose of user testing was to identify current workflow problems. Twelve participants (six pilots and six maintenance engineers) reflecting a spread of both domain and computer expertise were used. Tests were conducted in a quite room at AMT offices. Participants accessed Flightman^{TM} (version 1) using a portable tablet device. Relevant aircraft and flight information was pre-populated on application screens. Also, participants were provided with all necessary flight information (e.g. doctored flight plans, fuel and schedules). During the pre-test orientation, participants were instructed to imagine that they were using the application in real terms (e.g. keep to actual time constraints and consider other work requirements). Also, participants were asked to highlight workflows that failed to support real world situations (e.g. delays in getting information, requirements to repeat tasks based on last minute changes, etc.). Performance measures (time to task, error/success rates) were tracked, along with the participant opinions.

User testing helped uncover specific task workflow problems. Many of these related to task relationships which were overlooked in current workflow designs—Flightman^{TM} (version 1). Particular issues were probed in post-test interviews; this was more a case of problem identification and explanation than problem solving. Test times did not allow participants to consider re-designed workflows or the wider application model, in much detail. Despite efforts, the tests could not replicate the actual flight/aircraft turnaround work situation [dependent on context, dynamic, time constraints, often collaborative work (e.g. both crew collaboration and collaboration between flight crew and flight operations, despatch, maintenance and air traffic control (ATC))] or environment (e.g. subject to interruptions, noise levels). Given this, performance measures and related usability ratings were weighted carefully—time to task, numbers of errors and the overall application perception might change if used in a real environment.

4.2 Ethnographic interviews

Next a series of semi-structured interviews were conducted. The purpose of user interviews was to obtain an overall sense of task workflows and elicit problems around the paper process. Obviously method limitations were considered (e.g. reporting bias). A total of 15 participants were interviewed (9 pilots, 6 maintenance engineers). Participants were recruited through industry contacts and customer airlines (e.g. Futura Air). Some of the interviews were carried out in a quiet room at AMT offices. Others were carried out at customer sites (either before or after flight/turnaround observations, as time allowed). Interviews were helpful in terms of eliciting information about task workflows and clarifying some of the practical task issues which were noted during user testing (e.g. task relationships, time constraints). Although participants provided some useful ideas around improvements to the paper process, the interviews did not generate any concrete ideas for future EFB interaction (e.g. EFB model or screen layouts). Evidently, discussions were conceptual, and specific technology features were not explored or analysed.

4.3 Ethnographic observations

User observations involved observation of the current practice (paper process) and EFB usage in customer trials (paper process used in parallel with the EFB), for both flight crew and maintenance engineers. Access for flight and turnaround observations was provided by customer airlines as well as airlines engaging in product trials at that time. In both cases, usability engineers rode the jump-seat during flight, and shadowed maintenance engineers in the aircraft turnaround. Where time allowed, questions were posed around specific workflows observed.

4.3.1 Current practice

The purpose of observing the current practice was to validate the issues raised by participants in user interviews and to uncover any other issues that may have been overlooked. A total of 15 flight legs and 7 aircraft turnarounds were observed. Observation of the paper practice helped clarify the strengths and weaknesses of this process and how these might be factored into the re-designed work practice and supporting technology. Observations were also useful for eliciting data around group work and task workarounds given current work practice/tools constraints.

4.3.2 Customer trials

The purpose of observing Flightman™ (version 1) usage in customer trials was to investigate how well the product performed in practice, and to identify whether problems identified during user testing of Flightman™ (version 1) were replicated in customer trials. When tested out of context (laboratory setting) some problems may be overlooked or de-emphasised, while others may seem more important than they actually are. A total of 20 flight legs and 10 turnarounds were observed.

Observations of Flightman™ (version 1) usage in customer trials did not reflect real world practice—both paper tools and Flightman™ were being used in parallel. Some airlines split this task between the crew members (e.g. captain and co-pilot/maintenance engineers using either paper process or demonstration EFB). Certain airlines were concerned about the additional workload on flight crew and recruited a separate pilot to ride the jump-seat, using the EFB at appropriate times and keeping to task constraints. As there were no live customers, and flight simulators were not available, this was the only means to observing actual product usage. Despite obvious constraints, it was felt that some 'real life' feedback was better than none. Methodological issues such as these arise in commercial research. The point is to work around these constraints and weight the results carefully (consider how limitations might affect results). In this case, it involved interviewing participants informally after observations to review events and obtain further feedback on issues observed. Certainly, observations were informative in terms of understanding group work dynamics and actual work context. It must be noted that pilot workflows depend on context, and a complete task picture would require extensive observations (Hutchins 1995).

4.4 User and task analysis

Collectively, both phases of the research were analysed. The output of this analysis was a list of tasks, task scenario narratives, personas, hierarchical task analysis drawings and general EFB HCI rules (e.g. consistency, flexible workflows, etc.). Although useful from user/task/context perspective, these outputs were not instructive from a design perspective (e.g. in terms of describing an overall application model, or delineating the relationship between tasks and sub-tasks and between application screens and functions). With this in mind, participatory design techniques were considered.

4.5 Participatory design

4.5.1 Overview

Participatory design methods were used to solve problems regarding usability issues which arose in user testing and ethnographic research, and to provide a concrete interaction design model for Flightman (version 2). PD activities involved a combination of requirements' envisionment and the co-creation and evaluation of prototypes. There were four specific PD phases, involving four participants per phase (specific procedures are described in more detail below). Participants included flight crew, maintenance engineers, training personnel and domain experts. Individual sessions were conducted for all participants. Informal group sessions were conducted with AMT project stakeholders/management, after each PD phase, to relay project progress and elicit feedback on specific design decisions.

As participatory design work progressed, design feedback was relayed to software developers. After phase 2, a provisional model (EFB visual/interaction prototype) was provided to software development teams. Specific task interactions were translated into formal use cases and UML models by development teams. Later, user interface design and HCI rules (series of behaviours for different widgets and screen elements) were drafted. Both the design model and HCI rules were updated as research progressed. This often necessitated software edits. This was not ideal from a software development perspective (e.g. time and costs rewriting code), but was unavoidable given project requirements (e.g. software development and HCI research to progress in parallel with on-going HCI feedback and updates).

4.5.2 PD phase 1

The first phase involved developing a conceptual model for Flightman™ (version 2). A task was described and users were requested to outline the workflow and information requirements (including workarounds and bottlenecks and so forth). For example, participants were asked "If you noticed a new defect on landing, what would you do? What usually happens?" Participants were also encouraged to verbalise workflows and sketch task-flows, using pencil and paper. As part of this, participants were invited to consider group/collaborative work requirements. Further, participants were shown task workflow drawings (specific user and task analysis outputs) and asked to edit them, where appropriate. This led participants to scrutinise both their own conceptions of workflows, and that of others. This is close to Carroll's (2000) investigation of task scenarios via claims analysis. This resulted in a clear task picture (e.g. task hierarchies, sequences and relationships).

4.5.3 PD phase 2

The second phase involved the collaborative design and evaluation, of basic paper prototypes drawing from Muller's PICTIVE technique (Muller 1991; Muller and Kuhn 1993). In Muller's technique, users actively participate in the design of the user interface. Typically, users mock up a design (either individually or collectively) using basic materials (e.g. pencil, markers and paper), with the assistance of designers and/or developers. The mock-up/prototype is modified repeatedly (users evaluate the mock-up and solve the problem related to changes) for a specific time period. Often, the session is videoed to record the specific design iterations and the rationale behind proposed changes. Underlying this technique is the idea that users must experience the proposed technology solution (e.g. either by prototyping the solution or interacting with the solution), to properly critique the emerging work practice and supporting technology solution.

In this context, individual participants were invited to draw concepts for specific screens/workflows. Videotaping was not used. Some participants had difficulties visualising basic screen structures. In these instances, drawings were produced collaboratively (usability engineer and participant). After a number of participant sessions, generic drawings emerged (e.g. integration of results across a number of sessions). In later sessions, participants were asked to compare their drawings with the evolving concept. Again, this encouraged participants to explore complementary workflow concepts and related visualisations. Following on from this some Visio prototypes (generated from Microsoft Modelling Tool) for specific task scenarios were developed based on the emerging EFB concept.

4.5.4 PD phase 3

A third phase involved detailed evaluation of these prototypes. First, participants were asked to appraise a simulation of certain interaction concepts explored in phase 1. After this, participants evaluated specific screens/workflows. All participants evaluated the same prototype. Where problems arose, 'on the fly' design changes were made to clarify solutions. Individual problems and recommendations were recorded for each evaluation and analysed.

4.5.5 PD phase 4

A further Visio prototype was designed, based on the findings of phase 3 co-evaluations. The final phase, phase 4, involved further collaborative evaluations of the Visio prototype. Individual evaluations were conducted and problems and solutions recorded. The output of this phase was a tentative model for Flightman^{TM} (version 2). Currently, software developers are developing high fidelity prototypes for both roles (maintenance and flight crew), on a module-by-module basis.

4.6 Volpe evaluation

The Volpe National Transportation Center is a research organisation within the US Department of Transportation. Since 1998, Volpe researchers have been researching the human factors issues related to the design of EFBs. Specifically, Volpe researchers have produced guidelines for use by FAA evaluators, system designers/manufacturers and operators about the many EFB human factors considerations that need to be addressed during the design and evaluation of EFBs (Chandra et al. 2003). The FAA (2003) has drawn on this research in its EFB advisory circular. Volpe researchers have also devised a specific EFB human factors evaluation tool and methodology, which is being developed for use by the US Federal Aviation Administration, for the human factors evaluation of electronic flight bags (Chandra 2003).

High fidelity prototypes (outlined in previous section) were informally evaluated by a team of Volpe researchers, using the EFB human factors evaluation tool and methodology. These evaluations have yielded some informal design recommendations to enhance system usability. In the future, EFB development will be punctuated by a series of formal usability evaluations. Evidently, this will become a crucial part of EFB design projects, and integral to both HCI and software development processes (Chandra 2003).

5 EFB usability issues and solutions

5.1 Overview

Overall, the key usability issues to emerge in both user testing and ethnographic research related to information accuracy and currency, system structure and intelligence and task workload. PD activities focussed on resolving these issues using collaborative prototyping and evaluation techniques. A summary of these issues and related solutions is detailed in Table 1. A more detailed discussion of specific usability issues and solutions generated in PD activities is provided in the sections below.

5.2 EFB usability issues and solutions

5.2.1 Information accuracy and currency

Throughout research, users raised concerns about information accuracy and currency. Put simply, how

Table 1 EFB usability issues and solutions

Issues	Solutions
Information accuracy and currency	
Developing user trust	Dashboard displays last and next communications time
Communicating EFB information currency and validity	Inclusion of static textual instruction to remind users to communicate when required
	Inclusion of modal dialog window to prompt users to communicate when required
System structure and intelligence	
Perceived low system intelligence	Display of purposeful information driven by aircraft status e.g. dashboard screen
Confusing workflows	Low-level automation e.g. pre-populated fields
Inefficient workflows	Inclusion of context-sensitive prompts
Overall application structure unclear	Flexible workflows
	Application structured into individual task modules which contain contextual links to other task modules where appropriate (task relationships)
	Inclusion of dashboard with links to individual task modules
Workload	
Paper is faster than EFB/EFB increases workload	Read/review model
	Clarity in presentation of field types e.g. pre-populated and read only,pre-populated and editable, blank fields
Specific data input widgets frustrating or difficult to use	Re-design of entry widgets e.g. time control, calendar control
	On-screen keyboard features context sensitive keywords
	Inclusion of A–Z filter which sorts on first column of all lists, to allow for fast selection of list item

might they judge whether EFB information was up to date and valid. How could they ascertain the reliability of EFB information and therefore trust flight calculations and other critical data? Given current Flightman^{TM} implementation, (portable, not integrated with flight deck), this is a valid concern. Users noted that EFB information would require updating during aircraft turnaround (e.g. to update flight planning information, notices or documents). Further, if maintenance engineers and flight crew were using separate devices, device synchronisation would be required.

These problems were re-articulated as design problems. For example, how could the interface visually communicate information currency or communication requirements? Initial participatory modelling involved experimentation with a number of visual cues. All participants noted that the dashboard should clearly display the last and next due communication time. Many participants suggested displaying the due communication time in red, to alert users. Participants noted that the system should provide prompts to remind users of communication requirements (should they miss static visual cues). Obviously, visual cues must be consistent with regulatory guidelines, and suggestions were weighted as such (Chandra et al. 2003; FAA 2003). Currently, the dashboard presents last and due communication times and a highlighted textual instruction. Further, communication prompts are displayed in modal dialog windows, at appropriate times (Fig. 2).

5.2.2 *System structure and intelligence*

The question of system intelligence was raised by many participants. What level of intelligence should the system present? What level of user control is required (how passive or active should the user be)? Of significance here, is end user experience with other technologies (e.g. flight deck, flight planning systems, mobile devices and so forth). How might this instruct EFB design? Should there be consistency in terms of intelligence and interaction styles (taking into consideration device constraints)? During user testing, participants expressed surprise at the systems that perceived 'low intelligence level'. Interestingly, intelligence was described in terms of human-friendly features e.g. prompts as to required actions and the display of purposeful information, driven by aircraft status.

One of the key things to understand was the relationships between different functions (in terms of tasks and specific contexts), and how EFB interaction might support this. For example, wizard-style interaction

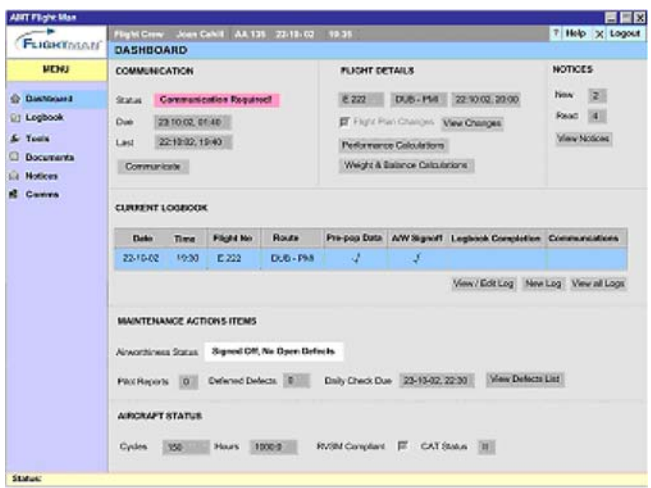

Fig. 2 Prototype of dashboard (first screen)

might seem appropriate for the logbook. However, if we consider broader task inter-relationships (e.g. the relationship between making flight calculations and recording flight calculations), flexible workflows are required. Users noted that the task model should take inspiration from the aircraft turnaround concept. Further, the overall design should allow for user control and flexibility. This led to the dashboard concept—an opening screen containing task status information and links to specific tasks.

Selecting functions from static nested lists was perceived as easier than selecting options from cascading menus. This was attributed to the constraints of pen/stylus interaction. Users also noted that menu visibility enhanced EFB usability. Given this, a web-based model (mix of hierarchical and contextual navigation) is used. EFB functionality is organised into a series of individual modules. These modules are listed on a menu bar using both text and icons (equivalent to primary navigation in Web metaphor). Specific modules correspond to broad tasks (e.g. logbook completion). Each of these modules contains sub-modules corresponding to specific sub-tasks (e.g. recording fuel information in the logbook). Also, where appropriate, task screens contain cross references (contextual navigation) to other functions. Further, users noted that interaction prompts (messages to complete tasks at particular times) would improve system usability. For example, after completing the logbook, users should be prompted to communicate. These are also included.

5.2.3 Task workload

Throughout initial user testing and ethnographic observations, Flightman™ (version 1.0) was perceived as less efficient than paper; data input was perceived as slow and frustrating. Participants felt that Flightman™ increased workload rather than reducing it. This was especially evident when participants entered defect descriptions. Descriptions were entered using a soft alphanumeric keypad. Users were required to build sentences by way of repeated single key presses.

PD techniques focussed on envisionment of efficient and user-friendly data entry methods. Overall the goal was to reduce user data entry requirements and develop a model where the primary interaction would involve data selection and/or review (e.g. users review and accept, and/or edit pre-populated data, or select data from pre-populated options lists). First, specific data requirements were captured. This included identifying the scope of EFB intelligence: what information is pre-populated and read only, or pre-populated and editable (user review requirements), or selectable from combo fields (given closed data ranges). Obviously visual clarity in terms of distinction between field types is important (Fig. 3).

Further, existing data entry widgets were evaluated and re-designed (e.g. time control, calendar, etc.) and further widgets envisaged (e.g. airport and crew lists). The solution involves relatively few data entry fields, and the use of a range of widgets designed for specific data requirements. Ensuring consistency between widgets (in terms of interaction style) is critical. Right now, this is an open problem, and an alternative integrated data entry widget is being modelled. To accelerate data entry, the soft keypad includes context-sensitive keywords. Participants noted that specific descriptions would vary according to user task and role. Specific keywords appropriate to particular user scenarios were identified, and a short-list of keywords agreed. Participants observed that the system might display frequently used keywords (e.g. client/server intelligence). Also, the system might record new words entered manually using the soft keyboard. Further, participants commented that keywords would be airline specific (configurable feature) (Fig. 4).

In addition, intelligent features presented in other mobile devices (e.g. personal digital assistants) were discussed and prototyped. This resulted in the creation of a generic 'A to Z' filter, which automatically sorts on the first column of all lists (amongst other context-based sorts) (Fig. 5).

6 Discussion

6.1 Advantages of PD methods

6.1.1 Technology envisionment

Task outcomes and human experiences implicitly set the agenda for new technological artefacts. This, in turn, alters subsequent task outcomes and experiences (Carroll 2000). Accordingly, if technology is not envisioned and evaluated in terms of potential impact on future work practices, it is fated to being 'stuck' in the task artefact lifecycle (Carroll 2000). Evidently, the

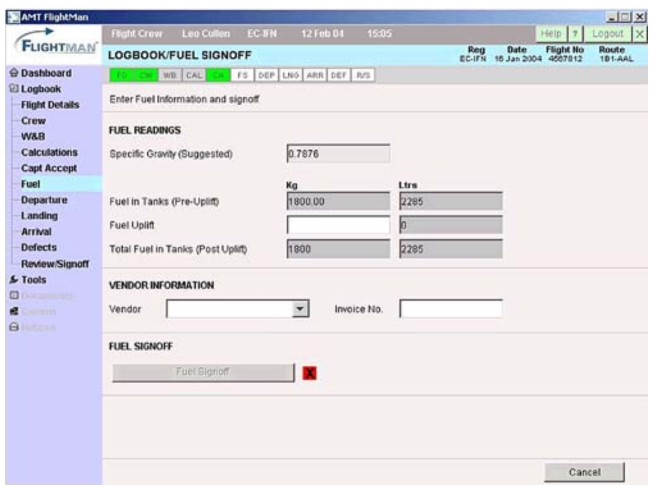

Fig. 3 Prototype of logbook fuel screen

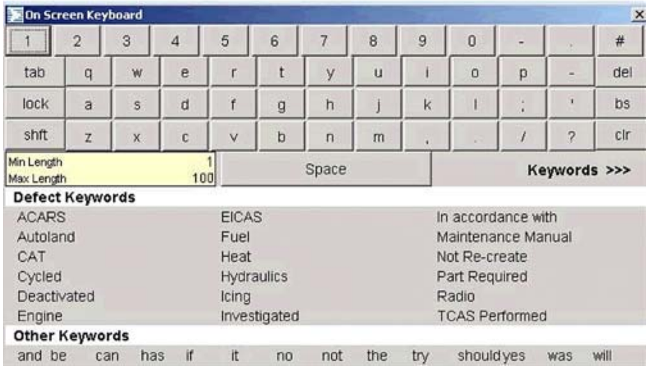

Fig. 4 Prototype of on-screen keyboard (defects scenario)

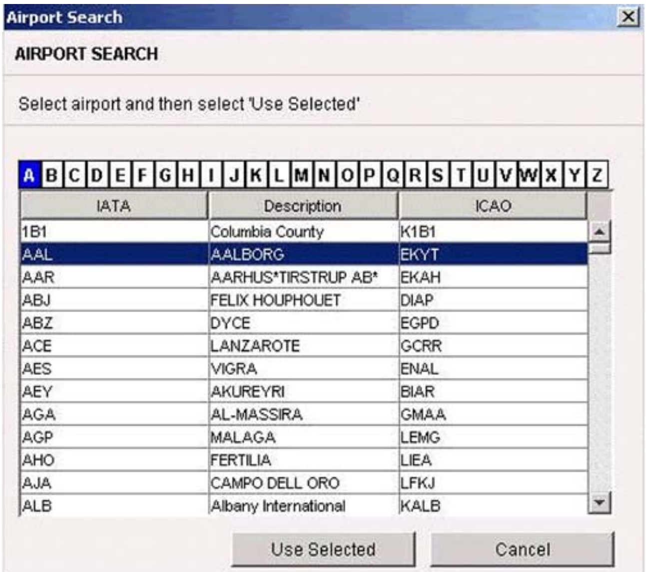

Fig. 5 Prototype of airport list

emphasis in PD methods, on experiencing and evaluating future work practices and related technologies, before development takes place, helps overcome these problems.

In commercial environments, there is pressure to 'get it right'—retrofitting a design model is costly. In the context of EFB development, it is difficult for usability engineers to 'get it right first time'. Given envisionment requirements (devising tools supporting future work practices), some kind of 'hands-on' collaboration with end users is necessary. Indeed the specific project experience proved just that. Task scenarios (outlined in user and task analysis phase) were far removed from the end solution. Further, early user interface design models (developed using PD techniques) were draft ideas and required rigorous evaluation and re-design.

6.1.2 Concrete design instruction

As evidenced in this project, the gap between requirements analysis (user and task analysis) and visual/interaction design is not easily bridged. Task narratives and workflow diagrams were not instructive in terms of identifying the relationship between tasks and sub-tasks and between application screens and functions. Further, these outputs were not useful for resolving specific interface design issues. As shown, collaborative modelling and evaluation of EFB solutions with end users provided a much needed design instruction. Prototypes were used as a basis for exploring, evaluating and communicating design ideas. Indeed, participants would not have been able to fully envisage and evaluate design ideas without such prototypes. Essentially, techniques allowed both users and designers to experiment with different visual/interactive affordances (e.g. menu structures, icons, presentation of form fields) until a design consensus was reached. Further, certain visual and interaction issues required 'hands-on' problem solving (e.g. data entry widgets).

6.2 Disadvantages of PD methods

6.2.1 Ecological validity

Clearly, the ecological criticisms directed at formal HCI methods, also apply to PD methods. PD methods do not involve the study of actual practice and technology usage in real work environments. Obviously, the envisionment and weighting of design solutions requires an understanding of actual work tasks and contexts. Usability engineers cannot rely on participant descriptions of practice and associated problems alone. For this reason, ethnographic research is a necessary first step. As shown, prior ethnographic research (user interviews and observation) provided necessary context information. This was used to direct and weight initial requirements-gathering discussions.

6.2.2 Bias: interpreting problems and identifying solutions

In PD methods (as with other HCI methods), there is much room for bias, in terms of evaluating end user problems and agreeing solutions. Usability engineers must remain neutral. If we are to design 'with users', we must learn from them, and not prejudge problems. Further, we must implement solutions on the basis of what is best for end users (and not just the solutions that we like or suggest). However, if a participant (or a group of participants) rates a solution positively, it does not mean that it is necessarily a good one. During PD sessions, participants proposed many conflicting solutions and the selection of specific user interface features was not straightforward. Adjudicating between design solutions involved drawing on usability expertise and generic usability principles (Constantine and Lockwood 1999). In this experience, generic solutions reflected a synthesis of user ideas.

6.2.3 Establishing trustworthiness

This raises the larger problem of establishing trustworthiness. Can we validate PD outputs? PD evaluations are not quantifiable scientific experiments. The quality of the emerging PD solution can be calculated (in some part), through user testing—by evaluating performance measures (such as time to task, error rates, ease of learning) and broader satisfaction ratings. This is where formal HCI methods are important. As mentioned, once developed, the EFB model will be user tested (phase 2 of research). These tests will include new participants in addition to the existing panel. The inclusion of new participants is crucial; we need to examine whether workflows are effective for persons previously uninvolved in the design process. Nonetheless, formal user testing is not enough; the product must be rated usable from the perspective of actual work practices. For this reason, additional ethnographic observations will be carried out at customer 'go-live'. If users have difficulties completing tasks 'in real life' further re-design will be required.

6.3 HCI methods in applied research

To date there has been no empirical study comparing the efficacy of participatory design methods with formal methods in HCI. This has been acknowledged by PD advocates (Muller 2003). It could be argued that to judge the merits of PD methods over formal HCI methods would necessitate a comparative evaluation of the outputs of both research methods, within the context of a product design or re-design project. This might be a useful theoretical exercise. However, it is unlikely to be undertaken by software vendors whose goals are practical (product development and not a study of research methods). This is not to say that commercial projects (such as this one) cannot contribute to the discussion of HCI methods. Indeed case studies such as these generate awareness on the efficacy of different HCI methods (both formal and informal), from an applied perspective.

The primary objective of practitioners working in business environments is to choose HCI methods which are pragmatic in terms of providing concrete user interface design instruction, while at the same time taking into account research validity/integrity and keeping to project constraints (time, budget). As such, it is not about subscribing to specific methodologies (e.g. either formal or informal HCI methods), but rather drawing upon the range of complementary HCI methods, selecting the most suitable and adapting methods where appropriate. In this example, participatory design methods were necessary for product envisionment and to help solving EFB usability problems. However, given the limitations of PD methods (ecological validity, establishing trustworthiness, etc.), both ethnographic interviews and observations and user testing were also required.

7 Conclusions

The development of EFB systems requires the application of a range of HCI methods, appropriate to EFB envisionment, design and evaluation. As shown, participatory design methods facilitate technology envisionment and provide concrete design instruction. Collaborative prototyping allows researchers to elicit feedback on future technology supporting improved work practices and circumvent the task artefact lifecycle. Further, it results in meaningful requirements; conceptual rules are translated into actual interface features and behaviours. In this way, research does not stop short of concrete solutions. However, as a stand-alone methodology, participatory research methods are insufficient.

Ethnographic research is a necessary precursor to PD methods, so that PD work can be directed and evaluated from the perspective of 'real life' practice. In order to interpret and weight participant opinions related to specific design solutions, researchers must be familiar with the existing problem space. To design tools that improve upon current practice, we must start from current practice; the design output is evolutionary not revolutionary. In this way, there is an appropriate timing for participatory research.

Further, formal HCI methods, such as user testing, have a critical role, in terms of an overall HCI methodology. User testing can be used to identify problems with current technologies/work practices and to validate proposed solutions (that is, the output of participatory activities). However, given the limitations of user testing (ecological validity), EFB models must also be evaluated in context (e.g. ethnographic observation). In addition, the EFB model should be customised for specific customer airlines.

The 'applied' HCI methodology presented in this paper is appropriate to the development of EFB systems (e.g. the envisionment of future work practices and the design of supporting work technology). Potentially, these methods may prove helpful for broader systems envisionment and design. Moreover, they may be useful for HCI researchers working in commercial software environments with applied research goals.

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