5-7-2019

Human Factors Electronic Kneeboard Design Guidelines for Military Tactical Aviation

Robert Bridgeman

Kelly J. Neville

Lauren Massey

Curtis Krauskopf

Ali Mizan

See next page for additional authors

Authors
Robert Bridgeman, Kelly J. Neville, Lauren Massey, Curtis Krauskopf, Ali Mizan, John Mooney, and Dylan Schmorrow

HUMAN FACTORS ELECTRONIC KNEEBOARD DESIGN GUIDELINES FOR MILITARY TACTICAL AVIATION

Robert Bridgman[1], Kelly J. Neville[1], Lauren Massey[1], Curtis Krauskopf[1], Ali Mizan[1], John Mooney[2], and Dylan Schmorrow[1]

[1] Soar Technology, Inc.
Orlando, Florida

[2] BGI, LLC
Dallas, TX

Great strides have been made in reducing the reams of paper-based materials that pilots were once required to bring into the cockpit. Much of that paper-based information is now available to pilots on electronic devices known as electronic kneeboards (EKBs). The main goal of this paper is to describe a design strategy we are using that integrates interdisciplinary perspectives and engages users in the design process. We describe the use of this design strategy to specify and design EKB applications (i.e., *apps*) that are uniquely supportive of the work demands faced by tactical pilots. As a result of the work described herein, we will be integrating multiple apps in support of high level goals, i.e., developing *super apps*. Future work will focus on developing these super apps so that they are responsive to situational changes. Future work additionally includes addressing key challenges associated with navigating within the EKB information space.

The advent of handheld computing devices dramatically changed the aircraft cockpit. In addition to changing the way pilots obtain information, it opened the door to a great deal more information and functionality. Originally used to give pilots easier access to the reams of documentation they brought into their cockpits, these electronic devices have continued to grow in both popularity and capability. They now feature a wide and still-growing variety of applications designed to give pilots easy access to information that previously required extensive search in their manuals or provide additional information that they may not have even had accessible.

Although the goal of using electronic knee boards (EKBs) sounds straight forward; give pilots easy access to useful information when they need it, achieving it is quite challenging. In particular, designing a device that supports dynamic and complex cognitive work, involves multiple parallel threads of activity, which is not directly observable. In addition, the design of the EKB's pilot interface matters greatly. Not only do EKBs bring easily accessible informtion into the cockpit but they also introduce the risk of increased workload, distraction, confusion, and head-down time. The outcome achieved depends heavily on the design used to implement the capabilities.

Designing to support complex, cognitive work relies heavily on deep user involvement and an iterative design process that involves frequent user testing in domain-relevant contexts. Notably, the design team was aware that there would be resistance to adopting these digital technologies as replacements for what many believe are "perfectly functional" physical tools. In order to address this potential barrier, we ensured that the design team had deep and relevant experience in the target-use domain of military tactical aviation. Additionally, evaluations with targeted end users were conducted in a way that focused on how cognitive work is performed versus on how a proposed EKB design would fit into their work. This helped to mitigate potential resistance to the proposed digital replacement technologies.

The goal of this paper is to describe a design strategy that engages users in the design process to both achieve a user-centered design and minimize the common and challenging obstacle of user resistance to change. This strategy includes the composition of our team, our design methods, and techniques we used to obtain user inputs and feedback.

Methods

Design Team and Philosophy

The design team consists of members representing multiple disciplines and perspectives, as advocated by Woods and his colleagues for design in complex technology-rich work domains (e.g., Roesler, Woods, & Feil, 2005; Woods, Tittle, Feil, & Roesler, 2004). Our team consists of three pilots (one licensed private pilot, one U.S. Navy Reserves F/A-18 pilot, and one former U.S. Navy MH-60 pilot), two software engineers, and two human factors psychology professionals. Two team members have experience in more than one key area: one pilot is also a software engineer and another has a graduate degree in human systems integration.

Design negotiations among the team members facilitate the interdisciplinary sharing of a wide range of design possibilities, constraints, and decision criteria, all of which contribute to effective design. According to Roesler et al. (2005):

> Balancing across the perspectives on design from the point of view of practitioners, innovators, and technologists presents a rich structure of relationships that can encourage innovation that results in more useful products (p. 211).

In our team, these design negotiations have tended to take the form of brainstorming sessions led by the two military aviators. As the two discuss their ideas about where and how in their work different EKB functions, or *apps*, could be useful, the other team members ask questions and take notes. Discussions about high-level work-support needs periodically segue into discussions about specific app designs, at which time the rest of the team participates more fully. The human factors and software engineering professionals at this point contribute ideas about how a given design might be implemented and scoped and raise questions about design interactions with work demands and general usability. Following each brainstorming session, individual team members develop design artifacts or prototypes based on the discussions, and these typically are presented and used as a point of discussion in the next brainstorming session.

The iterative, multi-disciplinary approach meant that designs are continually evaluated from three critical perspectives. These are the same perspectives advocated by Woods et al.: a technologist (our software engineer), a cognitive engineer (our human factors professionals), and a reflective practitioner as problem holder (our team's pilots). There may be an infinite number of ways to design an EKB or EKB app that supports fighter pilots but many will not integrate well into the work and work environment. The joint participation of these three types of perspective-holders allows us to develop and evolve designs that are more likely than others to succeed; more likely because the multidisciplinary team is able to pre-emptively identify and negotiate many of the competing priorities, constraints, and affordances that a successful design needs to address.

Subject Matter Expert (SME) Evaluation

Design evaluation sessions were conducted with five former military pilot volunteers who were paid a consultant's rate for their time. The sessions focused on the usefulness and usability of EKB designs in the context of single-seat tactical aircraft piloting. Two research team members, a Navy Reserves F/A-18 pilot and a human factors professional, met with each pilot for approximately one hour. Each pilot was asked to participate in two of three evaluation activities (time did not permit participation in all three). These activities were designed to obtain:

- Feedback on icons used to represent an initial set of identified apps,
- Insight into how and when pilots would use the apps (and therefore would expect the apps and their information and functionality to be readily available to them), and
- Feedback on the design of a *grading app* to be used by instructors in the grading of training flights.

The two activities in which each pilot participated were chosen on the basis of the pilot's expertise (e.g., one pilot was an instructor and so was shown the grading app) and on the activities conducted in preceding sessions to ensure that data from each activity were obtained from at least three pilots. Because of the qualitative, semi-structured nature of each evaluation activity, different amounts of time were spent by each pilot on each activity.

The remainder of this paper focuses on the evaluation and design of EKB app icons and functionality, i.e., the first two of the above list of bullets. (Information about the grading app design and evaluation can be obtained by contacting the authors.)

Icon feedback. In this evaluation activity, the pilot was told he would perform a series of app icon searches. For each trial, the pilot was shown an app icon. After studying the icon for roughly 3 to 5 seconds, a research team member removed the cover sheet over a matrix of icons positioned on the pilot's right thigh, at which time the pilot was to search the matrix and announce when he found the target icon. Icons in the matrix included distractor icons in addition to the full set of actual app icons. A different matrix of randomly positioned icons was used for each trial. An example of this matrix configuration is shown in Figure 1.

We did not collect search performance data as our focus was on pilots' design feedback and recommendations. We asked each pilot about his subjective experience of searching for the icon. Specifically, we asked the pilot to rate on a 5-point scale if the icon was easy or hard to find relative to other icons and to think about and discuss characteristics of the icon contributing to the assessed difficulty. Pilot responses were recorded by one of the research team members using pen and paper.

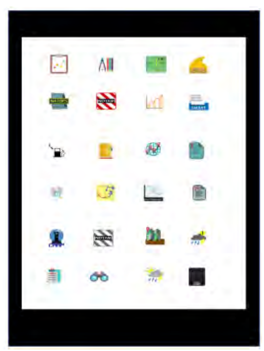

Figure 1. An example of the matrix of icons presented to SMEs.

Insight into when and how pilots would use the apps. For this evaluation activity, pilots were given a description of the purpose of each proposed app while being shown a laminated cut-out version of the app's icon. Each app's name was included on the icon cut-out. Pilots were then given the full set of 15 icons and asked to organize them into groups of apps they considered similar (we did not define 'similar' and instead left the choice of what counts as similar to the individual pilot). Each pilot was given multiple copies of each icon cut-out and a stack of blank paper rectangles and a pen. They were told they could use the copies to place icons in more than one grouping and that they could use the pen and paper to add additional apps to the set. Each pilot explained his groupings to the research team members while creating them and elaborated further after completing them. One research team member took hand written notes as they spoke.

Results

Application Groupings

Each SME was given an opportunity to group app icons into self-defined categories (see, e.g., Figure 2). These groupings provided insight into how and when the pilots anticipate using each app and suggested additional apps that the development team hadn't considered.

Four of the SMEs created groups of apps that centered around three main types of pilot activity: the tactical mission, navigation and administrative work, and non-normal or emergency conditions. Table 1 displays a specific grouping created by the fifth SME, who introduced the idea of first and second tier applications within a major activity category. This adds another layer of organization on top of the situation-specific groupings in which apps are organized soley by pilot goal or activity set.

Figure 2. An example icon grouping**.**

Table 1.
Example Application Grouping

Preflight	Inflight: First Tier	Inflight: Second Tier
Standard Instrument Departure (SID) app	Changes in relevant data, including: -Notifications about degraded weather conditions -New NOTAMS related to pilot's flight path	Performance charts/calculator
Weather app	Bingo support (e.g., nearby runways and fuel required to reach them)	NATOPS
Notice to Airmen (NOTAM) app	Pilot's scratchpad	Navigation charts
Aircraft Discrepancy Book (ADB)	Yellow Brick Road, i.e., course rules, app	Smart Pack
Geo-Scratchpad	Annotatable briefing and air combat maneuver (ACM) rules (i.e., frequently used reference documents)	Grading apps
	Standard arrival (STAR) charts	Flight log

Thus, a primary finding of this research is the recommendation of *super apps* that integrate numerous functions in service of a particular aircrew goal. A given function may be integrated into more than one super app; however, active function features presented to the user will be specific to the overarching goal and thus will vary by super app. Super-app concepts that emerged from the data include the following:

- *Emergency super app*. This app would provide aircrew with an integrated flow of resources for responding to emergencies. It would present relevant checklists, weather information, airfield and fuel information, aircrew performance charts, navigation charts, and other navigation tools and would do so in a way that minimizes extra work by the aircrew.
- *Mission super app*. This app would support inflight tactical planning and performance and may also support the debriefing of the tactical portion of a mission. It would feature an integrated suite of apps that aircrew would use to sketch out and view the tactical game plan; access weapons delivery profiles; view tanker locations and engagement zones; and record shot data, merge data, and more.
- *Inflight Guide super app*. The Smart Pack app would be an app that assists aircrew with navigation and administrative aspects of a mission. It would draw from flight guidance sources to present or highlight relevant route details, weather, NOTAMS, communications frequencies, patterns, routine checklists, and more along an aircrew's route.

A second major outcome of the research is the recommendation that the aircrew kneeboard card, i.e., mission line-up card, be continuously available at a central point of reference. SMEs recommended its use as a kneeboard 'homepage' in conjunction with an electronic scratchpad that the aircrew member could switch to via a sideways swipe. The kneeboard card lists the key basic elements of the mission at hand to help aircrew keep track of, for example, who is doing what when and what communications on which frequencies will mark their progress.

Conclusions

In this research, multiple SMEs interacted with our initial design elements to help us determine how to improve their fit to the demands of their work environment. SMEs responded positively and encouraged the integration of the various functions and features into super apps. Accordingly, in the next phase of this project, we will focus on integrating multiple functions to produce super apps, starting with the Emergency super app.

'Super apps' consist of more features, information, and functionality than individual apps and each new element represents many new possibilities for interaction with existing elements and aircrew. Further, although a super app's functions are all used in support of the same high-level objective, the conditions surrounding their use may change dramatically over the course of a mission. Consequently, we expect adapting super app designs to the complexities and variability of the flight environment to be an extensive process. To support this process, we are seeking flexible design, engineering, and evaluation methods that facilitate the development of complex integrated, interactive, and context-responsive capabilities.

Our near-term work also must address design challenges associated with supporting aircrew in interacting with and viewing the contents of the real estate-limited kneeboard apps.

Major challenges to be addressed have surfaced in this study and been reiterated in literature the team has reviewed. In particular, panning and zooming have, to date, not served as effective means for helping pilots view details on charts, checklists, and other information sources that are much larger than the mini iPad display (e.g., Chandra & Kendra, 2009; Sweet et al., 2017). We need to either develop alternative mechanisms for improving content visibility or add mechanisms that compensate for problems encountered when panning and zooming on navigation charts especially, but also on other resource material. Currently, we are evaluating one such alternative—the use of touch-based magnification bubble overlays—and need to continue working to identify other possibilities.

Similarly, navigation among pages and functions is far from straightforward given the quantity of content, the reasons any given content element might be relevant to the pilot, and the multiple ways different elements relate to one another. Research suggests current navigation schemes may pose safety hazards (e.g., Evans et a., 2013). Thus, it is imperative that we design improved techniques and tools for helping pilots keep track of what it is they are looking at, what they have recently seen and how to get back to it, and what's available that they might want to see or use next and how to get to it.

Acknowledgements

This research was sponsored by the Naval Aviation Training Systems Program Office (PMA-205). The views expressed in this paper are those of the authors and do not represent the official views of the organizations with which they are affiliated.

References

Chandra, D. C., & Kendra, A. (2009). Review of safety reports involving electronic flight bags. *Proceedings of the 15th International Symposium on Aviation Psychology*. Dayton, OH: Wright State University.

Evans, E. T., Young, S. D., Daniels, T. S., & Myer, R. R. (2013). Usability of EFBs for viewing NOTAMs and AIS/MET data link messages. In *Digital Avionics Systems Conference (DASC), 2013 IEEE/AIAA 32nd* (pp. 2A2-1). IEEE.

Roesler, A., Woods, D. D. & Feil, M. (2005). Inventing the Future of Cognitive Work. In W. Jonas, R. Chow, N. Verhaag (eds.), *Design-System-Evolution: Application of systemic and evolutionary approaches to design theory, design practice, design research and design education*. Bremen, Germany: European Academy of Design.

Sweet, J., Vu, K. P. L., Battiste, V., & Strybel, T. Z. (2017). The Comparative Benefits and Hazards of EFBs and Paper Documents in the Cockpit. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 61, No. 1, pp. 99-100). Sage CA: Los Angeles, CA: Sage.

Woods, D., Tittle, J., Feil, M., & Roesler, A. (2004). Envisioning human-robot coordination in future operations, *IEEE Transactions on Systems, Man, and Cybernetics: Part C, 34*(2), 210-218.