ASSESSMENT OF THE USE OF ELECTRONIC FLIGHT BAGS FOR DISPLAYING ENHANCED TRAFFIC AND WEATHER INFORMATION ON THE FLIGHT DECK

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Abstract

We evaluated the use of Electronic Flight Bags (EFBs) to provide enhanced traffic and weather displays on the flight deck. Scan path data of one pilot participant showed the expected crosschecking when weather information was displayed separately from traffics. In addition, displaying the weather and traffic information separately lengthened the time taken to make route modifications around weather and negatively impacted the quality of those modifications. As the use of EFBs to provide necessary capabilities to the flight deck may be inevitable, the present results suggest that their introduction should be monitored closely for potential impacts on task performance.

1 Introduction

The present research investigates issues concerning the incorporation of enhanced information displays on the flight deck that support tasks required in future airspace operations. New flight deck technologies and tools will be vital in order to meet the projected multi-fold increase in traffic demands for air travel in the coming decades [6]. However, there are immediate practical issues associated with retrofitting aircraft currently in service. A possible solution is to make the additional capabilities available on an auxiliary platform; for instance, Electronic Flight Bags (EFBs).

1.1 Use of EFBs on the Flight Deck

EFBs were developed by commercial airlines in the 1990s for presenting supplemental flight information traditionally provided in paper formats [5]. The market for EFBs underwent accelerated expansion after the U.S. Federal Aviation Administration (FAA) published an advisory circular on EFBs providing guidelines for their certification, airworthiness, and operational approval [4]. Today EFBs come in a variety of form factors and software/hardware capabilities [2]. They have evolved beyond offering digitized information previously only available on paper and are now widely used as a medium to funnel new information to the flight deck, such as aircraft performance calculation and weather displays [1].

While having access to old information in a more compact format, or to new information related to flight operation, could certainly benefit pilots, the introduction of EFBs to flight decks does not come without potential pitfalls. For example, Chandra and colleagues caution that one must assess the impact of EFBs on workload as part of the design consideration [2]. They note that new capabilities could increase workload if there is no accompanying procedure in place to help pilots utilize them efficiently. Likewise, the display of new information may not be as beneficial as anticipated when it is presented on a separate platform that requires attention and efforts to integrate with other information sources on the flight deck.

1.2 Present Study

The present research examines how EFBs might be used to equip the flight deck with advanced traffic information. In the U.S. plan for the Next Generation of Air Transportation System (NextGen), pilots may sometimes be responsible for maintaining safe separation from other aircraft as well as from hazardous weather conditions, while controllers will be responsible for managing the overall traffic flows (Joint Planning and Development Office, 2010). To support pilots' new roles and responsibilities, the flight deck needs to be equipped with advanced tools to support conflict detection and resolution (CD&R) and route planning, in addition to weather avoidance. A prototype of such an advanced traffic display, the Cockpit Situation Display (CSD), has been developed at the Flight Deck Display Research Lab at the NASA Ames Research Center. The CSD is a traffic display that supports both traditional 2D and advanced 3D and 4D visualization models. Incorporating dynamic trajectory prediction, it depicts the 4D interrelationship of traffic, terrain, and weather within the airspace using a cylindrical volume metaphor, thus enabling 4D trajectory-based operations (Figure 1). Additionally, the CSD provides automated CD&R, as well as other tools, which support the evaluation and implementation of route modifications. The current CSD implementation is manipulated using a computer mouse.

Figure 1. A screenshot of CSD displaying radar weather, traffics, and conflict alerts

The present research contrasted two methods of integrating EFBs on the flight deck. In both methods, CSDs were made available on two EFBs (emulated on two 14" touch screen monitors) mounted alongside standard cockpit displays in a Boeing 777 mid-fidelity flight simulator. To evaluate whether the CSD can be used effectively when implemented separately on EFBs, we contrasted conditions where weather information was integrated with traffic information and CD&R tools on the EFBs (Integrated condition), or where traffic and CD&R remained on the CSD but weather information was presented on the traditional Navigation Display (ND) in front of the pilots (Distributed condition). This contrast is of interest because weather is currently certified for and hosted on NDs, and certification of weather together with traffic on EFBs is likely to bring additional expense. Therefore, as a practical matter, this study should give some insight into the human factors costs and benefits of this integration. In general, implementation of advanced displays may involve showing relevant information across multiple displays and platforms. Intuitively, it seems to the authors that information of spatial nature from different sources that needs to be considered concurrently would best be presented together in an integrated fashion. Crosschecking would be necessary when information is distributed. The question is whether and how crosschecking interferes with operation performance when the pilot could not view information in the optimal way.

To evaluate crosschecking behaviors, we monitored gaze positions of one pilot participant flying simulated scenarios in the simulator. Analyses focus on segments of the scenarios during the en route phase of the flight wherein the pilot needed to examine traffic and weather information and then use CSD tools to make route modifications around weather.

2 Method

This study was part of a large-scale distributed human-in-the-loop simulation that involved an additional eight desktop pilot stations, two pseudo-controllers, and several pseudo-pilots. During the simulation the pilots conducted en route weather avoidance followed by a merging and spacing task during a continuous descent approach (CDA) into Louisville International Airport (SDF) (see Dao et al.'s [3] for a more detailed description of the simulation). The present paper focuses on the eyetracking data collected in the 777 simulator.

2.1 Participant

One U.S. corporate B737/757/767 line pilot with between 1000-3000 hours of glass cockpit experience participated in the study as the captain and was compensated $25/hr. The participant had no previous experience in flying a CDA but had previous experience in using the CSD.

2.2 Apparatus

The study was conducted in a mid-fidelity fixed-base Boeing 777 flight simulator configured with a full flight console, power quadrant, pedals, side-by-side seats, and four 50 inch plasma displays for the out-the-window view. The console is outfitted with avionics and glass cockpit displays similar to those standard on the real 777 airliners. The simulator is driven by multiple high performance personal computers (PCs), linked together through a distributed local area network (LAN). The PCs enable the running of a mixture of proprietary and off-the-shelf software that includes the flight management system (FMS), instrument display applications, user interaction modules, and the graphics for the simulated out-the-window viewing. In addition, the cockpit was equipped with two touch-screen displays (Winmate G-WIN Rugged Display, model R10L100-VMM3) that served as EFBs, one mounted at the captain side and one at the first officer side. They are 10.4” SVGA panels running a screen resolution of 1024x768 pixels. Touch sensitivity is transmitted through a parallel port. The CSD display interface was implemented on the EFBs and manipulated using computer mice accessible by the right hands of the crew on armrests.

Eye movements were monitored using a faceLAB face/eye tracking system (Seeing Machines, Australia). The system consists of two pairs of remote cameras mounted at strategic locations on the console to capture the captain’s gaze looking at the ND and the EFB. The system samples eye positions at 60Hz.

2.2 Designs and Scenarios

The scenarios began in the en route environment approximately 1.5 hour west of SDF at a cruising altitude of 33000 to 39000 feet with a planned descent into the airport. All experimental aircraft conducted complete CDA arrivals into SDF. After crossing the “freeze horizon” (approximately 600 nm from SDF), or immediately after the scenario began for planes that began the scenario within the freeze horizon, an arrival information message was sent to all participating arrival aircraft. This message included a scheduled time of arrival (STA), a speed profile to fly that would meet the STA, and if appropriate, merging and spacing information. The merging and spacing information included the call sign of a lead aircraft, a spacing interval to be achieved behind the lead aircraft (105 seconds), and a merge point at which they would become in trail of their lead aircraft. Experimental aircraft pilots were told to engage automated spacing behind their lead aircraft at once they received the arrival information. The scenarios ended when the last of the experimental flights landed.

Convective weather cells were placed 15 to 30 minutes ahead of an aircraft’s starting point, depending on where the aircraft was in the merging and spacing sequence. Flight crews were responsible for determining when to engage, disengage, or reengage merging and spacing operations if interruptions in nominal arrival procedures occurred.

In addition to manipulating how weather information was displayed (Distributed and Integrated), the simulation varied across three types of weather (Dense, Sparse, and None). The two factors, weather display and weather type, were completely crossed, with two scenarios in each combination of conditions. Crosschecking was only expected when weather hazards were present in the scenarios; hence the analyses were limited to those eight scenarios. Because of technical problems, the runs for two scenarios, one with Integrated Dense weather and one with Distributed Dense weather, were incomplete. The analyses here will focus on four of the remaining six scenarios runs, one in each combination of weather display (Integrated and Distributed) and weather type (Dense and Sparse) conditions.

3 Results

Scan path analyses focused on the two displays of interests: EFB and ND (Figure 2). Table 1 summarizes the number of fixation transitions per minute among seven areas of interests (EFB/CSD, primary flight display, ND, primary engine display, datalink window, mode control panel, and left front window) and the number of transitions per minute specifically between EFB and ND during route modifications around weather in the four conditions. It is evident from the results that when weather information was integrated with traffic, the participant did no crosschecking and focused exclusively on the EFB. Figure 3 shows sample scanpaths of crosschecking and no crosschecking in distributed and integrated conditions, respectively.

Figure 2. A view of the captain seat with EFB (left), PFD (center), and ND (right).

The present results clearly demonstrate, as expected, the pilot engaged in frequent crosschecking between EFB and ND in the distributed condition to assimilate information needed for making route modifications on the EFB using the tools provided in the CSD. While the pilot could still perform the task, it is unclear whether this was done at the expense of operation performance. In order to assess whether there was any performance impact due to crosschecking, we compared the speed with which route modifications were made and the quality of these modifications across the two weather displays conditions. During each scenario, our pilot participant made between two to three route modifications to avoid weather and/or traffic conflicts. The total time spent on all route modification combined during each scenario is summarized in Table 1. While the number of route modifications did not vary widely between conditions (between two and three in each run), it is evident that our pilot participant spent considerably longer time modifying routes in the distributed conditions than in the integrated conditions. In addition, since the pilot spent on average around 90% the time looking at the EFB in the distributed condition, the increase in total time reflects mostly an increase in EFB viewing time. This increase was likely the result of the need to mentally integrate distributed weather and traffic information.

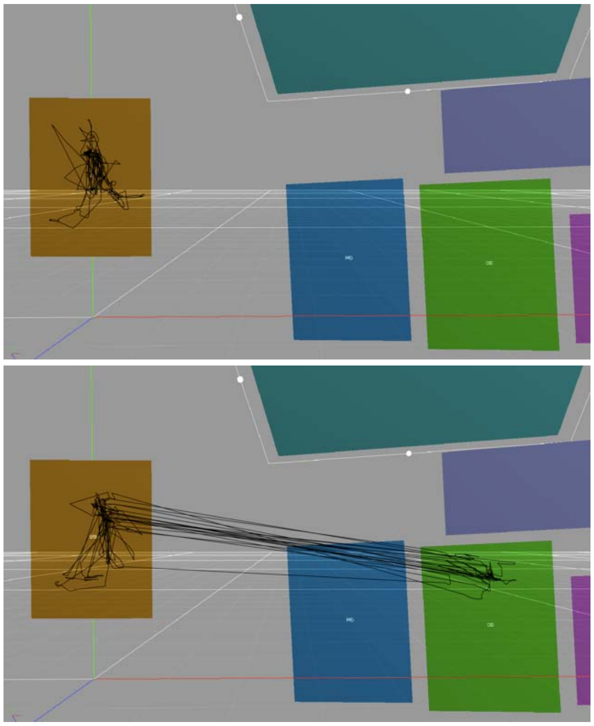

Figure 3. Sample scanpaths showing no crosschecking in the integrated condition (top) and crosschecking between EFB and ND in the distributed condition (bottom).

Table 1. Task performance and eye movement results in the four weather display and weather type conditions during route modifications

Weather Display Type	**Weather Type**	**Total Time on Route Mod. (min)**	**% Time on EFB (CSD)**	**% Time on ND**	**Num. of Total Trans. (per min)**	**Trans. from EFB to ND (per min)**	**Trans. from ND to EFB (per min)**	**Closest Distance to Weather (NM)**
Distributed	Dense	7.66	0.87	0.08	8.48	3.00	2.74	7.4
Distributed	Sparse	3.45	0.90	0.10	14.20	4.93	4.64	0.3
Integrated	Dense	3.47	1.00	0.00	0.87	0.29	0.00	6.1
Integrated	Sparse	2.53	1.00	0.00	0.79	0.00	0.00	19.4

The quality of the modified flight paths was operationally defined by the shortest distance between the outer edge of weather and the trajectory flown by the aircraft. The distance, measured in nautical miles (NM), are summarized in Table 1 as well. It should be noted that the FAA guidance for weather avoidance is to maintain 20 NM separation from all weather radar echoes. R. W. Koteskey, an United Airline pilot, noted that in actual practice this may not be always achievable and deviations are often just enough to stay out of the echo (personal communication, June 7, 2010). The present results ranged from 0.3 to 19.4 NM, corresponding to Koteskey's description. These results (from a single pilot) showed closer approaches to the weather cells when the route modifications involved crosschecking two displays. This pattern was especially pronounced when the weather cells were sparsely distributed and possibly more difficult to line up across displays. More research will be needed to establish if these findings are particular to this pilot, or if they reflect a general tendency among pilots.

4 Discussion

With changing roles and increased responsibilities, there will be a desire for future flight decks to possess all the capabilities that technology can offer, and EFBs will likely be the primary platform to implement them in early stages of deployment. The present research examined one such case, in which advanced traffic displays hosted on flight deck EFBs needed to be used in conjunction with weather information either integrated onto those same EFBs or presented separately on traditional NDs. The results from one pilot participant showed that, when relevant information was distributed between EFBs and NDs, the necessary crosschecking behavior likely lengthened the time needed to complete route modification and negatively impacted the quality of the resulting flight plans. Although cautions should be used in interpreting results obtained from a single participant and limited trials, they nonetheless echo Chandra and colleagues' concerns on the potential downside of EFBs when implemented and used without careful evaluation of their potential impacts [2]. As the use of EFBs to supplement necessary capabilities to the flight deck may be inevitable, more research will need to be conducted on a case by case basis to closely monitor how their introduction may impact task performance and to design procedures for incorporating EFBs into routine flight operations.

5 References

[1] Cahill, J., & Donald, N. M. (2006). Human computer interaction methods for electronic flight bag environment and design. *Cognition, Technology, and Work, 8,* 113-123.

[2] Chandra, D. C., Yeh, M., Riley, V., & Mangold, S. J. (2003). *Human Factors Considerations in the Design and Evaluation of Electronic Flight Bags (EFBs), Version 2.* Washington, DC: Office of Aviation Research.

[3] Dao, A.-Q., Lachter, J., Battiste, V., Brandt, S. L., Vu, K.-P., Strybel, T. Z., Ho., N., Martin, P., & Johnson, W. J. (2010). Automated spacing support tools for interval management operations during continuous descent approaches. Paper to be presented at the 54th Annual Meeting of the Human Factors and Ergonomics Society, San Francisco, CA.

[4] Federal Aviation Administration (2003). *Advisory Circular: Guidelines for the Certification, Airworthiness, and Operational Approval of*

Electronic Flight Bag Devices (AC No: 120-76A). Washington, DC: US Department of Transportation.

[5] Hirschman, D. Electronic flight bags. *Aircraft Owners and Pilots Association (AOPA) Pilot Magazine*, 2009.

[6] Joint Planning and Development Office. (2010). *Concepts of Operations for the Next Generation Air Transportation System.*

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