EXPERIMENTAL EVALUATION OF PORTABLE ELECTRONIC FLIGHT PROGRESS STRIPS

Nathan A. Doble and R. John Hansman, Massachusetts Institute of Technology, Cambridge, MA

Abstract

Air traffic service providers are increasingly embracing electronic alternatives to the traditional paper Flight Progress Strip (FPS). However, most development of such electronic systems, and of Decision Support Tools (DSTs) in general, has centered on radar-based en route or terminal-area facilities, rather than the airport air traffic control tower. Based on an analysis of the unique human factors requirements of the control tower environment, a prototype Portable Electronic FPS has been designed that also serves as an interface to a DST for departure operations. The Portable Electronic FPS has been implemented using a system of networked, handheld computers as prototype hardware.

A study has been conducted to evaluate the usability of the Portable Electronic FPS. The study consisted of a human-in-the-loop experiment that simulated the tasks an air traffic controller performs at a major airport. Three issues were explored: the importance of FPS portability, the appropriateness of departure sequence DST advisories distributed onto each Portable Electronic FPS, and the advantages of interaction mechanisms enabled by an electronic interface. Test subjects used multiple versions of the Portable Electronic FPS as well as a current-day paper FPS. Quantitative measures of departure sequencing efficiency and traffic monitoring ability were recorded for each test subject, as well as subjective FPS preference rankings.

This paper reviews the final design and prototype implementation of the Portable Electronic FPS, presents the design and results of the usability study, and suggests future research that should be pursued in order to create an operationally deployable Portable Electronic FPS system.

Introduction

The Flight Progress Strip

The paper flight progress strip (FPS) is one of the primary tools air traffic controllers use to monitor aircraft, along with radar, voice communication, and—at airport control towers—visual observation. It contains the flight information most important to a controller, such as the aircraft call sign, type, navigation equipage, and route of flight. Figure 1 shows an FPS used in airport control towers for departing flights.

Figure 1. FPS For Departure Aircraft

Controllers use handwritten FPS annotations to record clearances and organize the FPSs in a strip bay to indicate some relevant order in the air traffic under their control. As a flight passes through different airspace sectors, the FPS is also passed from controller to controller, either physically (in the case of airport control towers) or by electronically accessing the flight information and printing a new FPS (in the case of en route control facilities and inter-facility handoffs). In this way, the FPS acts as a surrogate for a flight as it moves through the air traffic control (ATC) system and serves as a partial record of the control actions that were taken.

Development of Electronic FPS Systems

Most electronic FPS systems developed to date have attempted to create an electronic analogue of the strip bay, with multiple electronic FPS representations shown on a single display. One example of such a system for en route ATC facilities is the DigiStrips project, in which FPSs are annotated via gesture recognition on a touch screen [1]. And although primarily designed as a

conflict probe and trial planning tool, the User Request Evaluation Tool (URET) has also been used as an electronic FPS interface [2]. For control towers at small, general aviation airports in Australia, the GAAP Flight Progress Monitoring System has been prototyped, using a mouse-based graphical interface [3].

Electronic FPS systems could have a number of advantages over paper FPSs, such as streamlined flight data recording and dissemination, greater interactivity, and the ability to interface with other ATC decision support tools (DSTs) [4]. However, many benefits of the paper FPS have been noted [5,6]. Such benefits include adaptability to facility-specific annotation methods, reliability (FPSs can be handwritten if flight data computers or FPS printers fail), a direct interface (writing on the FPS may be faster than keyboard- or mouse-based input methods), and portability.

The portable nature of the paper FPS has important implications for the ways in which controllers interact with the FPS and with each other. For example, physical possession of an FPS conveys ownership of a flight. Also, various strip bay positioning techniques are used to draw attention to certain flights and to construct abstractions of traffic flow structures. Portability is particularly important in the airport control tower environment, as it allows controllers to view and annotate flight information while simultaneously moving around the control tower cab, which is often necessary to observe aircraft and ground vehicles at various locations on the airport surface.

The Portable Electronic FPS Concept

Based on an analysis of the advantages and limitations of the paper FPS, the possible benefits of an electronic FPS interface, and the unique human factors requirements of the airport control tower environment, a concept has been developed called the Portable Electronic FPS [7]. The Portable Electronic FPS concept aims to replicate the core features of the paper FPS while incorporating the benefits of an electronic interface in a system that would be appropriate for operations in the control tower of a major airport.

The Portable Electronic FPS concept envisions a system of handheld electronic devices, each

representing a single FPS and transferring data via a wireless data network. In this way, instead of creating an electronic version of the entire strip bay, the individual FPS is preserved as a physical artifact. FPS data is transferred to and from a central Management Interface. The Management Interface displays information on overall airport operations and serves as an information conduit between the Portable Electronic FPSs, DSTs, and the Host flight data computer.

Portable Electronic FPS Prototype Design

Prototype Hardware and System Architecture

The Portable Electronic FPS concept has been prototyped using Compaq iPAQ Pocket PCs for the FPSs and a desktop computer for the Management Interface. While the Pocket PCs are not considered appropriate for a production system, they have a number of attributes that are useful for prototyping the Portable Electronic FPS design: they reasonably approximate the size of a paper FPS, they have a straightforward software development environment (Microsoft Embedded Visual C++), they have a touch screen for direct input, and they can be easily configured for wireless networking with add-on hardware. Figure 2 shows the prototype Portable Electronic FPS hardware and user interface.

Figure 2. Portable Electronic FPS Prototype

Although a Portable Electronic FPS system could be used in a control tower for both arrival and departure operations, the prototype displays have been designed for departures. This presented a more challenging design problem because, as they are used today, departure FPSs contain more

information, and are annotated more, than arrival FPSs. In addition, one of the primary goals of the Portable Electronic FPS research was to explore how an electronic FPS could be used as an interface to a DST. The MIT Departure Planner was chosen as the candidate DST for study. The Departure Planner improves departure throughput through optimized sequences and schedules for gate pushback, taxi, and takeoff [8]. Figure 3 shows the Portable Electronic FPS system architecture, including the Departure Planner.
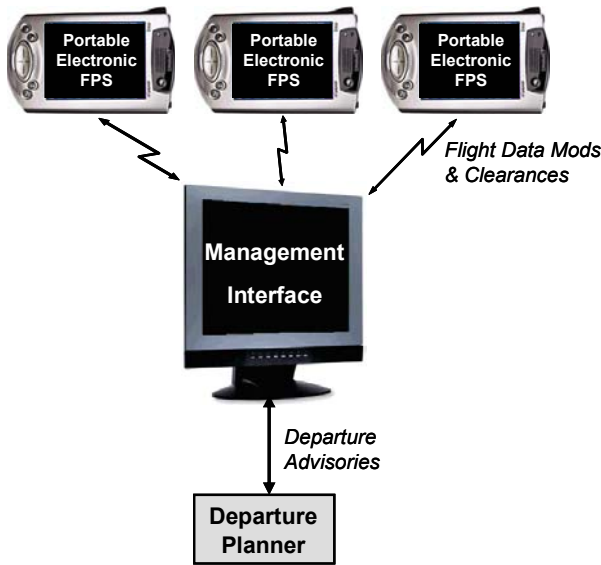

Figure 3. Portable Electronic FPS System Architecture

Portable Electronic FPS Display

Figure 4 shows an example screen capture from the Portable Electronic FPS display. The top half of the display replicates the flight data found on a paper FPS: call sign, aircraft type and navigation equipage, transponder code, gate, runway assignment, initial heading, initial altitude, cruise altitude, and route of flight. As shown in Figure 5, these flight data elements can be modified by highlighting a field with the Pocket PC stylus and selecting a new value from a pop-up menu. While the example in Figure 5 shows a basic, text-based menu, various other design alternatives for flight data modification have also been prototyped [9].

The upper-right corner of the display is a scratchpad area where controllers can write

miscellaneous or nonstandard annotations. This has been noted as an important feature of paper FPSs and has been included in the Portable Electronic FPS to retain display flexibility and adaptability.

The bottom half of the Portable Electronic FPS display contains information specific to the Departure Planner. This includes suggested times and/or sequences for departure events (gate pushback, taxi, and takeoff) and a list of downstream flow restrictions that impact the aircraft.

Along the bottom-right side of the display are "clearance buttons." These buttons are used to record clearances, replacing the need to write clearance times, as is currently required with paper strips. By tapping the clearance button with the Pocket PC stylus, the clearance times are automatically recorded. The displayed clearance buttons change based on departure status (e.g., the FPS for an aircraft at the gate will show a "clear push" button while the FPS for an aircraft at the runway will show "clear takeoff" and "position and hold" buttons). In addition, the clearance buttons are color-coded by sequence position; once an aircraft is first in sequence for a departure event, the clearance button for that event changes color from yellow to green. The aircraft callsign (in upper-left corner) is also color-coded by departure status (at gate, ready for push, cleared push, cleared taxi, cleared position and hold, cleared takeoff).

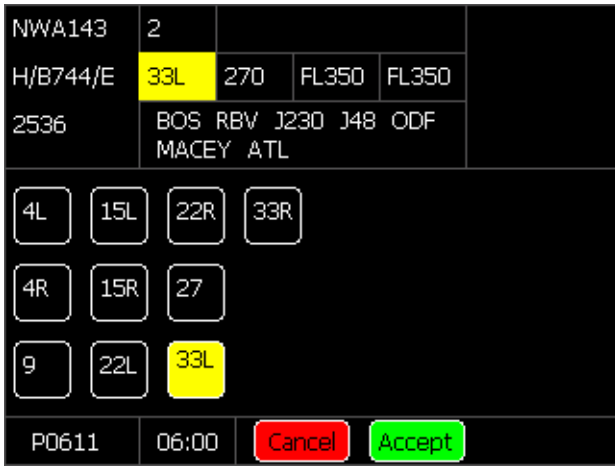**Figure 4. Portable Electronic FPS Display**

Figure 5. Departure Runway Assignment Menu

Management Interface Display

As currently prototyped, the Management Interface contains three primary elements: a display of departure advisories in a queue-style format, a listing of active departure flow restrictions, and an airport surface map showing aircraft positions. An example of the Management Interface is shown in Figure 6.
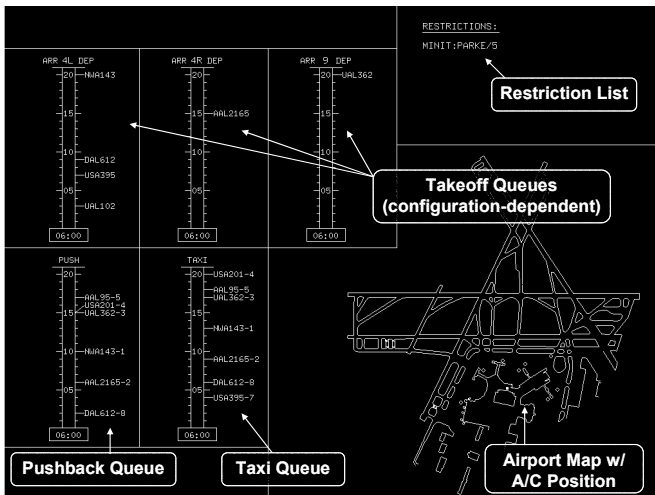

Figure 6. Management Interface

Two different formats have been prototyped for the pushback, taxi, and takeoff queues. The first format is time-based, and is modeled after on the NASA Center-TRACON Automation System TMA tool [10]. The second format, which was chosen for the Portable Electronic FPS usability study, is solely sequence-based. Both of these formats are shown in Figure 7. The queues display the aircraft

call sign and gate, color-coded by departure status. The same information shown on the Management Interface queues is also displayed in an aircraft-centric format on each Portable Electronic FPS, as discussed above. Whenever a clearance is issued (via the Portable Electronic FPS clearance buttons), the Management Interface departure queues are automatically updated.
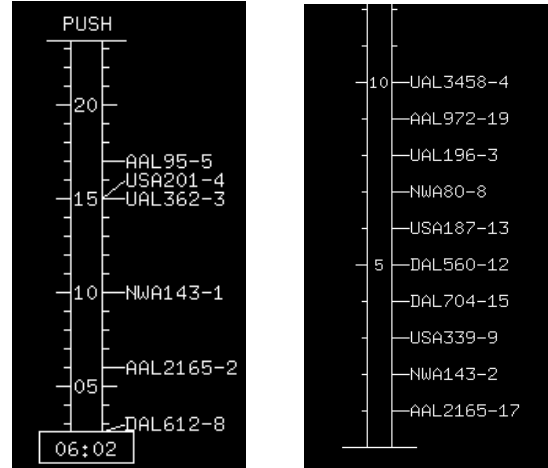

Figure 7. Time-Based (left) and Sequence-Based (right) Departure Queues

Experimental Evaluation

Goals

Broadly, the goals of the Portable Electronic FPS evaluation were to explore the usability of such a system in comparison to the paper FPSs currently in use, via subjective evaluations and objective performance measures of typical ATC tasks. Specifically, the evaluation was designed to address three questions: First, is the Portable Electronic FPS an appropriate interface for Departure Planner advisories? Second, how important is the portability of the Portable Electronic FPS? Third, how useful are the interface features of the Portable Electronic FPS, such as clearance buttons and color-coded aircraft departure status indicators?

Design

A part-task, human-in-the-loop simulation of an airport control tower's pushback/ground control position was developed. This simulation modeled the following controller tasks: sequencing aircraft

for departure, issuing pushback and taxi clearances via voice communication, using FPSs, and visually observing airport surface traffic.

Figure 8 shows the experiment architecture. Each test subject was given FPSs (paper or electronic, varying by test condition) for a set of 10 departure aircraft, as well as a Management Interface. The primary tasks of the test subjects were to use the information on the FPSs and Management Interface to construct an optimal departure sequence, implement this sequence by issuing voice clearances, and annotate the FPSs as the clearances were issued. The test administrator acted as a pseudopilot for all the departure aircraft, verbally requesting and responding to clearances. In each experimental scenario, the test administrator would request pushback for an aircraft approximately every 30 seconds. The test subject would then issue pushback and taxi clearances as appropriate to construct an optimal departure sequence, considering Departure Planner pushback and taxi sequence advisories when available. Each scenario continued in this manner until all 10 aircraft had taxied toward their departure runway.
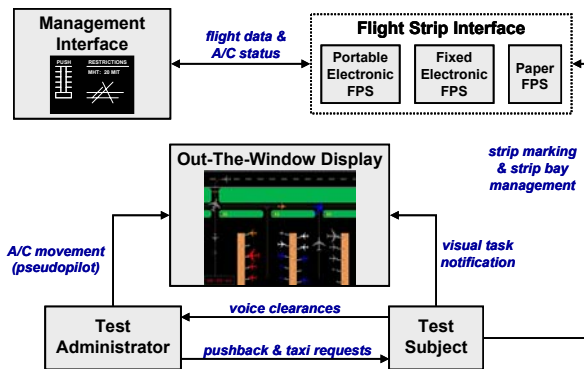

Figure 8. Simulation Architecture for FPS Evaluation

To simulate the visual environment of the control tower, a two-dimensional, top-down view of a fictional airport was projected on a screen in front of the test subject. This Out-The-Window View, shown in Figure 9, displayed portions of the airport terminal, gate, ramp, taxiway, and runway systems. As aircraft were given clearances, they were shown pushing back from their gates and taxiing toward the runway, with their movement controlled by the test administrator.

The Out-The-Window View also was used to watch for runway incursions, the test subjects' secondary task. Approximately every 10 seconds, an aircraft would taxi from the left edge of the Out-The-Window View, then either taxi toward the runway or toward the ramp area. Test subjects were instructed to stop any aircraft that taxied toward the runway (accomplished by pressing a key on the Management Interface keyboard). This secondary task was designed to measure the amount of time spent heads-down on FPS annotation.
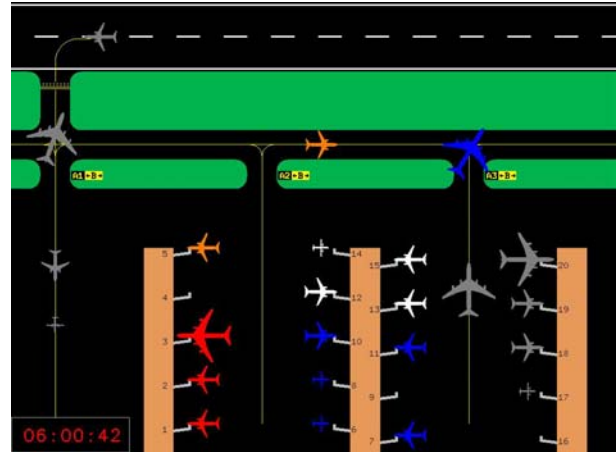

Figure 9. Out-The-Window View

Protocol

Each test subject was first given an introductory tutorial document to read. This explained the test subject tasks (including suggested methods for achieving an optimal departure sequence) and described how to use the paper FPS, electronic FPS, Management Interface, and Out-The-Window View. After the tutorial was read, the test administrator summarized the most important points of the tutorial and answered any questions. The test subject then completed practice scenarios with both the paper and electronic FPSs, followed by five data-collection scenarios. Test subjects also completed subjective questionnaires after each scenario and at the end of the experiment.

Independent Variable

The independent variable for the experiment was the type of FPS used in each scenario. Five different FPS formats were evaluated: (a) a replica of a current-day paper FPS, (b) a Portable

Electronic FPS with departure advisories on both the FPS and on the Management Interface, (c) a Portable Electronic FPS with departure advisories on the Management Interface only, (d) a Portable Electronic FPS without departure advisories, and (e) a fixed electronic FPS without advisories. Formats (a) and (d) were compared to determine the advantages of an electronic interface. Formats (b) and (c) were compared to determine the appropriateness of displaying Departure Planner advisories on the Portable Electronic FPS. And formats (d) and (e) were compared to determine the importance of FPS portability. Format (e) was identical to format (d), with the exception that test subjects were instructed not to pick up the electronic FPSs. This restriction was designed to emulate a fixed, touch screen based FPS display.

The experiment was designed in a repeated-measures format, with 10 test subjects completing a scenario for each of the five FPS formats. To compensate for practice and fatigue effects, the order of FPS format presentation was varied according to a balanced Latin square design.

Dependent Variables

For each scenario, quantitative dependent variables were measured to assess test subject performance on the tasks of departure sequencing and runway incursion monitoring. Written questionnaires were used to gather subjective data.

For the departure sequencing task, the total runway occupancy time was measured for the sequence of 10 departures constructed by the test subject in each scenario. This was compared against the optimal (i.e., minimum) total runway occupancy time, which was calculated using an approximation of FAA inter-departure wake turbulence spacing minima [11]. This resulted in a Time-Over-Optimal sequencing measure for each scenario.

For the runway incursion monitoring task, performance measures were recorded according to standard alerting system conventions [12]. The numbers of Correct Detections, Missed Detections, and False Alarms were recorded for each scenario, as well as Reaction Time (i.e., the time elapsed from the aircraft first turning toward the runway to the incursion being noted by the test subject).

Post-scenario questionnaires asked subjects to rate the difficulty of performing the departure sequencing and runway incursion monitoring tasks. On a post-experiment questionnaire, subjects provided data on FPS format preferences, most-liked and disliked attributes of the electronic FPS, departure advisory preferences, and electronic FPS portability preferences.

Experimental Results

Ten subjects completed the Portable Electronic FPS evaluation. All test subjects were graduate students at the Massachusetts Institute of Technology, either with pilot experience or air transportation research experience. None of the test subjects were professional air traffic controllers.

Objective Results

To answer the questions posed in the "Goals" section above, mean values across test subjects for departure sequencing performance (using Time-Over-Optimal data) and for runway incursion monitoring performance (using Reaction Time data) were computed for each FPS format. Table 1 summarizes these results.

Table 1. Mean Values for Departure Sequencing Performance (Time Over Optimal) and Runway Incursion Monitoring Performance (Reaction Time), by FPS Format

FPS Format	Mean Time-Over-Optimal (sec)	Mean Reaction Time (sec)
Paper	88.5	9.60
Portable Electronic w/ Advisories	126.0	9.74
Portable Electronic w/ Advisories on Management Interface	42.0	9.95
Portable Electronic w/o Advisories	100.5	10.42
Fixed Electronic w/o Advisories	136.5	8.88

The above data was compared in a pair-wise fashion across scenarios, using a two-sided Mann-

Whitney test at a 5% level of significance. The Mann-Whitney test was used instead of the Student's t-test because, due to the bounded nature of the performance measures, the data was not assumed to be normal. Table 2 shows the results for the departure sequencing task, and

Table 3 shows the results for the runway incursion monitoring task. The only significant performance difference found was for the departure sequencing task, in which test subjects performed better when using the Portable Electronic FPS with departure advisories only on the Management Interface, as compared to the Portable Electronic FPS with departure advisories on both the Management Interface and the FPS.

Table 2. Pair-Wise Departure Sequencing Performance, Two-Sided Mann-Whitney Test (5% Significance Level, z_{crit} = 1.96)

FPS Formats Compared			z	Significant?
Portable Electronic w/ Advisories	vs.	Portable Electronic w/ Advisories on Management Interface	2.87	Yes
Portable Electronic w/o Advisories	vs.	Fixed Electronic w/o Advisories	1.13	No
Portable Electronic w/o Advisories	vs.	Paper	0.30	No

Table 3, Pair-Wise Incursion Monitoring Performance, Two-Sided Mann-Whitney Test (5% Significance Level, z_{crit} = 1.96)

FPS Formats Compared			z	Significant?
Portable Electronic w/ Advisories	vs.	Portable Electronic w/ Advisories on Management Interface	0.23	No
Portable Electronic w/o Advisories	vs.	Fixed Electronic w/o Advisories	0.23	No
Portable Electronic w/o Advisories	vs.	Paper	0.22	No

Subjective Results

Quantitative results were tabulated for two subjective measures: scenario difficulty and FPS format preference. Table 4 and Table 5 summarize these results, averaged across all 10 test subjects. Test subjects rated the "Portable Electronic FPS with Advisories" scenario easiest and the "Paper FPS" scenario most difficult. Test subjects rated the "Portable Electronic FPS with Advisories" as the most preferred FPS format and the "Fixed Electronic FPS without Advisories" as the least preferred FPS format. And overall, nine out of ten test subjects preferred some variation of electronic FPS over the paper FPS.

Table 4. Mean Subjective Scenario Difficulty

FPS Format	Mean Scenario Difficulty (1 to 5 scale, 1 = easiest)
Paper	4.05
Portable Electronic w/ Advisories	2.70
Portable Electronic w/ Advisories on Management Interface	2.90
Portable Electronic w/o Advisories	3.60
Fixed Electronic w/o Advisories	3.55

Table 5. Mean Subjective FPS Preference

FPS Format	Mean Preference Ranking (1 to 5 scale, 1 = favorite)
Paper	4.00
Portable Electronic w/ Advisories	1.55
Portable Electronic w/ Advisories on Management Interface	2.35
Portable Electronic w/o Advisories	3.00
Fixed Electronic w/o Advisories	4.10

Practice Effects

Practice effects were observed according to several different measures. Figure 10 shows the Time-Over-Optimal runway occupancy times

averaged over all ten test subjects for each scenario, in the order that the scenario was presented to the test subject. Because a balanced Latin square design was used, each FPS format appeared twice in every presentation position. Even after completing the practice scenarios, test subject performance on the sequencing task monotonically improved as the subjects gained more experience during the data-recording scenarios. Similar behavior was observed for performance in the incursion detection task and for the test subjects' subjective difficulty ratings for each scenario.
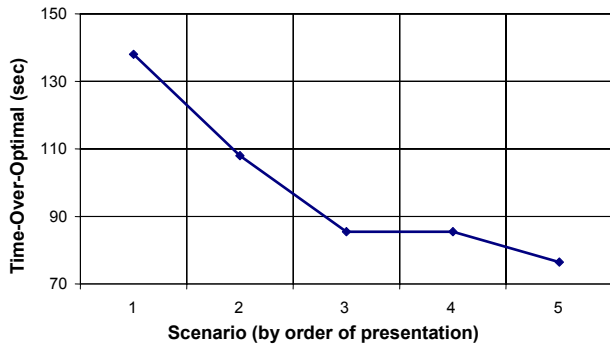

Figure 10. Practice Effects Observed in Departure Sequencing Task

In contrast, the test subjects' subjective rankings of FPS format preference did not appear to have any strong correlation to the order in which the FPS formats were presented. This data is shown in Figure 11.
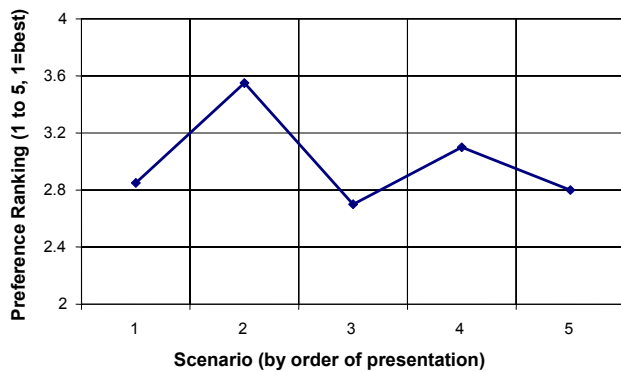

Figure 11. No Practice Effects Observed for FPS Format Preference Rankings

Discussion

The results of the FPS evaluation have highlighted a number of promising features of the prototype Portable Electronic FPS and have shown areas which need further research. In addition from the completion of the evaluation, much can be learned about what type of testing should be done in the future to elicit more substantive conclusions about the performance benefits of a Portable electronic FPS system.

First, according to subjective data, it is clear that test subjects much preferred an electronic FPS to a paper FPS. In a direct comparison (in which the electronic FPS contained the same information as the paper FPS), 70% of test subjects preferred the "Portable Electronic FPS without Advisories" to the "Paper FPS." And although it is difficult to compare different versions of the electronic FPS to the paper FPS (due to the varying amounts of information content and decision support), 90% of test subjects preferred at least one of the four electronic FPS formats over the paper FPS, with the clearance buttons being the most often mentioned reason. Although not confirmed by quantitative data, this seems to indicate that there are indeed advantages to input methods enabled by an electronic FPS interface. Furthermore, test subject free responses showed that most complaints about the Portable Electronic FPS were hardware-dependent. Such issues included the weight of the Pocket PC, the font size, the brightness of the display, and the form factor of the device. These limitations could be overcome through advances in display technology, discussed below.

On the issue of the appropriateness of displaying Departure Planner advisories on the individual Portable Electronic FPSs, the objective results would seem to indicate that departure advisories are better left to a centralized display. This is somewhat surprising, as the departure advisories on the individual FPSs only repeated the information shown on the Management Interface. However, the extra information could have confused the test subjects, and due to practice effects, many test subjects may have never developed a successful method for integrating the advisories on the FPSs with the advisories on the Management Interface. Also, it is conjectured that the appropriateness of distributed FPS Departure Planner advisories is closely tied to the fidelity of the advisories. To avoid excessive experimental complexity, the Departure Planner sequencing

advisories were fixed at the beginning of each scenario, and could not adapt to test subject deviations from the a priori optimal departure sequence. Furthermore, the advisories did not account for taxipath length differences, merging taxi stream effects, or blocking effects caused by gate positions. While this behavior was explained to the test subjects, it is speculated that the low fidelity of the departure advisories required the test subjects to take a "big picture" perspective, rather than considering each aircraft's departure advisories separately. This may have unintentionally reduced the utility of the advisories on the FPSs.

On the issue of the importance of FPS portability, two factors prevented more conclusive results from being obtained. First, in hindsight, the experiment was not designed in a way that would require subjects to make use of PFS portability. While the Out-The-Window view was presented on a large projection screen in order to more closely emulate the view from an airport control tower cab, a more useful design would have been to present the Out-The-Window view on a smaller, less proximate display, which would have required test subjects to walk to different positions in order to see the Out-The-Window view and the Management Interface. Second, the prototype Portable Electronic FPS hardware itself may have discouraged test subjects from picking up the FPSs. Many test subjects remarked on the weight of the Pocket PC displays. Indeed, with the addition of an expansion jacket to hold the wireless network card (and its associated extra battery), each Pocket PC weighed approximately one pound, considerably more than a paper FPS.

Finally, while practice effects were mitigated through the use of a balanced Latin square experimental design, practice effects were a large factor in test subject performance. These effects may have dominated the results and caused the lack of significant differences among sequencing task and runway incursion task measures. While more training would have been desired for this experiment, there was a tradeoff between the amount of training and the experiment duration. However, it would appear that more extensive training should be a part of any subsequent experiments. This also introduces the larger question of the best method to quickly evaluate the usability of a new system when the system is ultimately intended for the expert user. This is a question which is not addressed in this research.

Future Work

The experimental results suggest it would be difficult to conduct more detailed analyses of the benefits of a Portable Electronic FPS system while keeping the conclusions independent of the prototype hardware. Several technologies are emerging which may enable an electronic display that better emulates the reflectivity of paper, eliminating the need for a backlit display and the associated high power consumption and viewing difficulty under certain lighting conditions. Such technologies include cholesteric liquid-crystal displays and electrophoretic displays [13]. Decreasing power consumption would provide further benefits in terms of decreased battery weight or increased battery life.

This leads to other implementation issues which would have to be addressed before a Portable Electronic FPS system is operationally deployed. Such issues include the security of wireless transmissions, the method for keeping the batteries in the electronic devices charged, and the durability of the electronic devices. One possible solution to the issue of battery life would be to create a device which charges when it is placed in the strip bay. The strip bay could also be used to transfer information to and from the FPS, although this would preclude the ability to always display real-time information on the FPS. This is a significant limitation, especially when the integration of the FPS with an alerting system or DST is considered.

In addition to implementation issues, a number of display formatting and interaction mechanism alternatives for the Portable Electronic FPS should be considered. The utility of many of these alternatives was not explored in the evaluation of the Portable Electronic FPS. Further research should explore the areas of menu-based interaction vs. handwriting recognition, text-based menus vs. more graphical flight data modification methods, and sequence-based advisories vs. time-based advisories.

Further research should also engage air traffic controllers in the evaluation process. While some

informal input from air traffic controllers was used to guide the Portable Electronic FPS design, air traffic controllers were not available for the FPS evaluation. Using non-controllers for the experiment had the advantage that the test subjects did not already have extensive experience with one of the tested FPS formats. Using actual controllers may have biased the results in favor of the paper FPS. However, it is clear that the input of air traffic controllers is needed as the design of displays and interaction mechanisms becomes more refined, should the Portable Electronic FPS concept advance toward an operationally-deployed system.

Concluding Remarks

The design and evaluation of a prototype Portable Electronic FPS system has been presented. The design of this system resulted from an attempt to address the limitations and retain the benefits of a paper FPS, considering specifically the operational issues particular to the airport control tower environment. Using prototype hardware, displays and interaction mechanisms for the Portable Electronic FPS system were developed. A usability study was then conducted to determine the utility of the electronic FPS in comparison to paper FPSs. This study consisted of a human-in-the-loop experiment which simulated the tasks of an air traffic controller in an airport control tower environment. Specific issues explored during the experiment include the appropriateness of displaying departure advisories on the Portable Electronic FPS, the importance of FPS portability, and the advantages of interaction mechanisms enabled by an electronic interface.

Among the conclusions from the experiment, test subjects clearly preferred the Portable Electronic FPS to a paper FPS. However, more detailed results were confounded by the domination of learning effects and the characteristics of the prototype hardware itself. Further research should include more extensive air traffic controller input in the evaluation process, address implementation issues necessary for an operationally-deployed system to overcome, and explore emergent display technologies which may better emulate the physical characteristics of the paper FPS.

References

[1] Mertz, Christophe et al, 2000, "Pushing the Limits of ATC User Interface Design Beyond S&M Interaction: The Digistrips Experience", 3rd USA/Europe Air Traffic Management R&D Seminar, Naples, Italy

[2] Celio, J.C. et al, 2000, *User Request Evaluation Tool (URET) Benefits During Free Flight Phase 1*, The MITRE Corporation, report MP-99W0000183

[3] Ryan, Caspar et al, 2003, "Design and Usability Evaluation of a GAAP Flight Progress Monitoring System in a Simulated Air Traffic Environment", Australasian Computer-Human Interaction Conference, Brisbane, Australia

[4] Pavet, D., 2001, "Use of Paper Strips by Tower Air Traffic Controllers and Promises Offered by New Design Techniques on User Interface", 4th USA/Europe Air Traffic Management R&D Seminar, Santa Fe, NM

[5] Mackay, Wendy E., 1999, "Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control", ACM Transactions on Computer-Human Interaction, Vol. 6, Issue 4, New York, NY, ACM Press, pp. 311-340.

[6] Sellen, Abigail J., Richard H.R. Harper, 2002, *The Myth of the Paperless Office*, Cambridge, MA, MIT Press

[7] Doble, Nathan A., R. John Hansman, 2002, "Preliminary Design and Evaluation of Portable Electronic Flight Progress Strips", 21st Digital Avionics Systems Conference, Irvine, CA

[8] Anagnostakis, Ioannis et al, 2000, "Conceptual Design of A Departure Planner Decision Aid", 3rd USA/Europe Air Traffic Management R&D Seminar, Naples, Italy

[9] Doble, Nathan A., 2003, *Design and Evaluation of a Portable Electronic Flight Progress Strip System*, master's thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA

[10] Lee, Katherine K. et al, "Human Factors Report: TMA Operational Evaluations 1996 & 1998", NASA/TM-2000-209587

[11] de Neufville, Richard and A.R. Odoni, 2003, *Airport Systems: Planning, Design, and Management*, New York, NY, McGraw-Hill

[12] Kuchar, J.K., 1996, "Methodology for Alerting-System Performance Evaluation", Journal of Guidance, Control, and Dynamics, Vol. 19, No. 2

[13] Crawford, G., 2000, "A Bright New Page in Portable Displays", IEEE Spectrum, Vol. 37, Issue 10, pp. 40-46