

PRELIMINARY DESIGN AND EVALUATION OF PORTABLE ELECTRONIC FLIGHT PROGRESS STRIPS

Nathan A. Doble and R. John Hansman

International Center for Air Transportation

Massachusetts Institute of Technology, Cambridge, MA

Abstract

There has been growing interest in using electronic alternatives to the paper Flight Progress Strip (FPS) for air traffic control. However, most research has been centered on radar-based control environments, and has not considered the unique operational needs of the airport air traffic control tower. Based on an analysis of the human factors issues for control tower Decision Support Tool (DST) interfaces, a requirement has been identified for an interaction mechanism which replicates the advantages of the paper FPS (e.g., head-up operation, portability) but also enables input and output with DSTs. An approach has been developed which uses a Portable Electronic FPS that has attributes of both a paper strip and an electronic strip. The prototype flight strip system uses Personal Digital Assistants (PDAs) to replace individual paper strips in addition to a central management interface which is displayed on a desktop computer. Each PDA is connected to the management interface via a wireless local area network. The Portable Electronic FPSs replicate the core functionality of paper flight strips and have additional features which provide a heads-up interface to a DST. A departure DST is used as a motivating example. The central management interface is used for aircraft scheduling and sequencing and provides an overview of airport departure operations. This paper will present the design of the Portable Electronic FPS system as well as preliminary evaluation results.

Introduction

The FPS, along with radar, voice communication, and visual observation, is one of the primary tools controllers use to monitor air traffic. The FPS contains much of the information

about a flight which is relevant to a controller, including the aircraft's call sign, navigation equipment, route of flight, and cruise altitude. Figure 1 shows a tower FPS used for an aircraft departing an airport.



Figure 1. Departure Flight Progress Strip

Controllers use handwritten annotations on the FPS to update the information. They also organize the strips on a strip bay or other surface, with the strips positioned to indicate some relevant order of the air traffic, such as departure time, arrival time, or altitude. As control of an aircraft is handed off from one controller to another, the FPS is also passed from controller to controller, either physically (in the case of intra-facility handoffs) or by printing a new strip (in the case of inter-facility handoffs). In this way, the FPS acts as a surrogate to the aircraft as it moves through the air traffic control system and serves as a record of the control actions that were used for a particular flight.

The paper FPS has changed little since its introduction. The flight plan information on the FPS is now stored in a computer system and printed automatically instead of being written by hand, but annotations are still handwritten by controllers [1]. Efforts have been made to introduce electronic versions of the paper FPS into radar control facilities [2]. However, little work has been done on implementing an electronic FPS system in the airport control tower. The benefits and limitations of paper flight strips should be understood before determining both the benefits an electronic strip system may provide to the control tower, and the form such a system should take.

Benefits of Paper Flight Strips

While the FPS may initially seem to be an antiquated technology, many benefits of the paper FPS have been noted in relation to automated systems and computer displays. The paper FPS is flexible. It is able to accommodate changes in air traffic and changes in annotation methods. No two air traffic control facilities function exactly the same way, and the paper FPS can be easily adapted to facility-specific needs. The paper FPS is also reliable. The only failure point in the system is the strip printer. If the strip printer is not working, the information contained on the FPS can be written by hand [3].

The portable nature of the FPS also has important implications. Possession of the FPS, either by holding it or placing it in a controller's strip bay, conveys ownership of a flight. When a controller wants to draw attention to a particular flight, the position of the FPS in the strip bay can be offset [4]. As noted above, the paper flight strip enables intra-facility control transfers (e.g., between ground and local controllers in the control tower) to be performed by physically handing off the FPS to the next controller. In addition, the paper FPS supports controller visual accommodation. The controller can move the strip to simultaneously observe traffic out the window and look at or annotate the FPS, which minimizes head-down time. The paper FPS is also an interface whereby controllers can make annotations directly on the strip, which may have advantages over a keyboard or mouse input method [2].

Limitations of Paper Flight Strips

While the paper FPS has proven to be a useful tool for managing air traffic, it has a number of limitations. There is no direct data transfer between the paper FPS and any other air traffic control system. Thus, the information about aircraft state and intent which is shown and updated on the flight strip is not disseminated for use by other DSTs. Also, the paper FPS has limited interactivity. While the controllers can interact with the flight strip through handwritten annotations and can interact with other controllers through the flight strip, the paper FPS cannot react to the controller annotations or adapt by automatically changing the information displayed on the flight strip.

Possible Benefits of Electronic Flight Strips

Two possible benefits of an electronic FPS include better observability of control actions and the ability to directly interface with decision support tools [5].

Observability of Control Actions

Consider a basic air traffic control loop with current paper FPSs as shown Figure 2. The controller receives information both directly from surveillance (radar or visual observation) and through a DST. Based upon this information, the controller issues clearances to an aircraft via voice communication. Some clearances, such as flight plan amendments, may be input into the Host computer via Flight Data Input/Output (FDIO) equipment and could then be immediately known to the DST. However, many of these clearances, such as heading, altitude, and speed changes, and taxi clearances, are not directly available to the DST because they are either only recorded on the paper FPS or not recorded at all [3]. The DST either must indirectly observe these clearances through surveillance, or there must be a separate mechanism for the controller to input information into the DST.

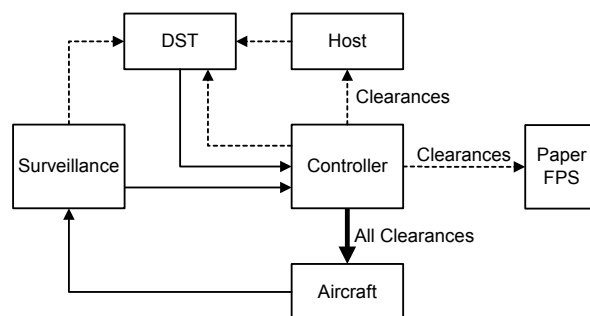


Figure 2. Basic Air Traffic Control Loop

However, an electronic FPS would enable the dissemination of more clearances, which could improve the utility of a DST. This information flow is shown in Figure 3. For example, the trajectory synthesizer of a conflict detection tool could use updated heading and altitude clearance information to construct more accurate trajectories. Another benefit of using the electronic FPS to record clearances is that a separate interface would no longer be needed to input flight plan amendments into the Host computer.

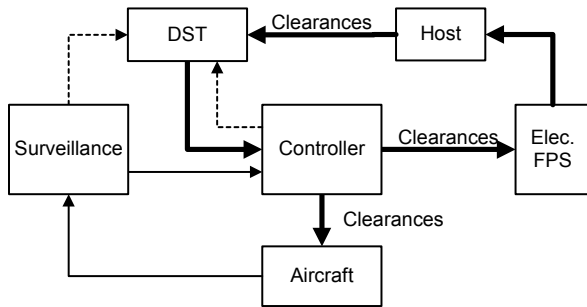


Figure 3. Air Traffic Control Loop with Electronic FPS

Flight Strip as DST Interface

An electronic FPS could enable the flight strip to be more than a device for displaying flight data and recording clearances. The electronic FPS could have greater interactivity and could act as an interface to DSTs, as shown in Figure 4. For example, a runway incursion alerting system could issue an alert via the electronic FPS as soon as a dangerous taxi or takeoff clearance is issued. This interface synthesis could reduce the number of displays a controller would need to monitor.

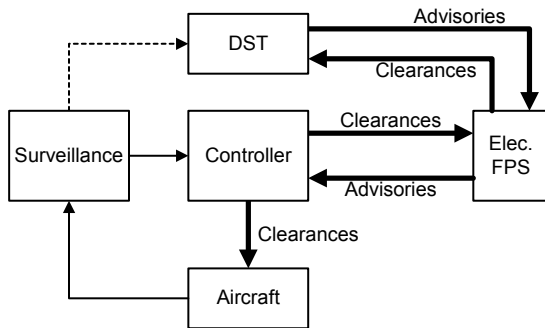


Figure 4. Air Traffic Control Loop with Electronic Flight Strip as DST Interface

Portable Electronic Flight Progress Strip Concept

An ideal flight strip should combine the benefits of both a paper strip and an electronic strip. To date, most electronic FPS concepts designed for radar-based environments have used a fixed monitor, possibly with a touch screen, to show electronic representations of multiple flight strips on a single display [2]. This approach creates an electronic analogue of the strip bay. However, in

the tower environment, a fixed display for multiple flight strips may not sufficiently replicate the human factor benefits of the paper FPS.

One approach that has been explored for combining the desirable qualities of both a paper and electronic FPS is to keep the paper strip but use a video camera or graphics tablet to record the information on the strips [6]. However, with continuing improvements in handheld computers and wireless networking, another concept is proposed. Instead of a single display replicating the strip bay, the Portable Electronic FPS system would use multiple handheld devices to display electronic representations of individual flight progress strips. Wireless communications would be used to transfer data to and from the flight strips. In this way, the Portable Electronic FPS would retain many of the benefits of the paper FPS.

Motivation

The prototype Portable Electronic FPS system described below is developed to evaluate the viability of the Portable Electronic FPS concept, both as a replacement for paper flight strips in the control tower and as an interface for a DST. The particular DST concept used to derive requirements for an interface is the MIT Departure Planner [7]. This DST would improve departure operations by issuing pushback, taxi, and takeoff advisories based upon optimal, “virtual” queues in order to increase departure throughput and reduce delays.

Design Process

Requirements Analysis

Two major categories of requirements were identified for the Portable Electronic FPS: core flight strip functional requirements (supporting the existing paper FPS functionality) and Departure Planner functional requirements (controller inputs and outputs for the DST).

Core Functional Requirements

The functionality present in paper flight strips which must be preserved in the Portable Electronic FPS includes [8]:

- Displaying the aircraft call sign, type & equipage, transponder code, route of

flight, cruise altitude, proposed departure time, and departure airport

- Changing the aircraft type, altitude, route, etc.
- Recording the initial heading
- Recording “ready to push” and departure times
- Recording in-trail restrictions
- Writing nonstandard taxi paths
- Indicating a wake turbulence waiver
- Indicating correct ATIS received by aircraft
- Indicating a position-and-hold clearance
- Recording any other nonstandard instructions

Departure Planner Functional Requirements

The inputs required for the Departure Planner are [7]:

- Aircraft “ready for pushback” time
- Actual gate pushback time
- Taxi start time
- Takeoff time
- Gate location
- Current runway configuration
- Downstream constraints

The Departure Planner interface will output:

- Virtual pushback queues
- Virtual runway queues, including runway assignments and suggested takeoff times
- Suggested runway configuration changes
- An airport surface map

Design Conclusions

The core and Departure Planner functional requirements can be organized into two categories: aircraft-specific, and airport-wide. Aircraft-specific elements include pushback, taxi, and takeoff times, gate locations, and runway assignments. Airport-wide elements include pushback queues, runway queues, and runway configurations. The Portable Electronic FPS is well-suited for showing aircraft-specific information. Indeed, some of the required Departure Planner inputs, such as the pushback and takeoff times, are already contained on paper flight strips [8]. However, airport-wide information has

been determined to be more appropriate for a centralized interface, rather than distributed throughout individual Portable Electronic FPSs.

The above observations led to the conclusion that a Departure Planner interface should consist of both the Portable Electronic FPS system and a centralized management interface, as shown in Figure 5.

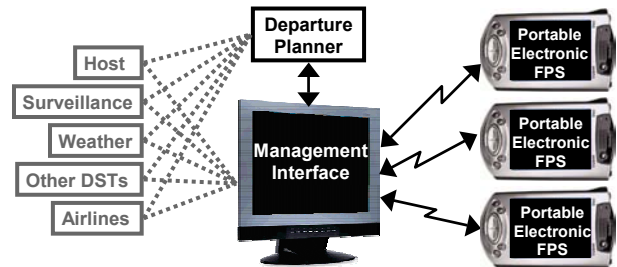


Figure 5. System Architecture for Departure Planner Interface

The Portable Electronic FPS will be used to receive individual aircraft departure advisories from the Departure Planner and to input clearances from the controller. The management interface will be used to display and change departure sequencing and spacing on an airport-wide level. Figure 6 shows an overview of the interaction and information flow between the air traffic controller, the management interface, and the Portable Electronic FPS.

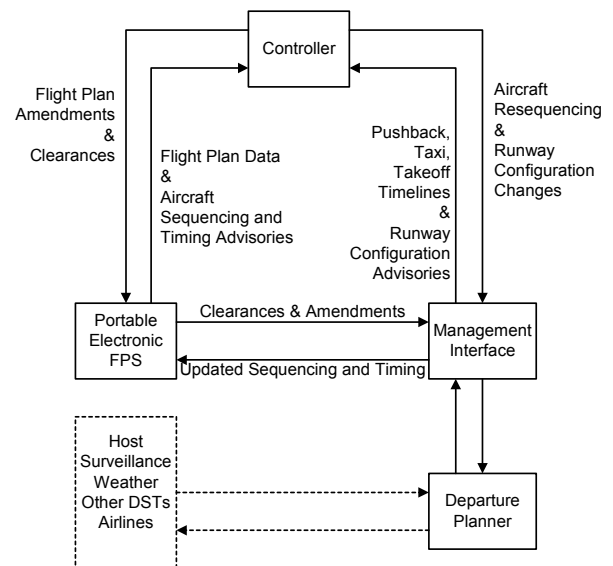


Figure 6. Interaction and Information Flow Between Controller, Portable Electronic FPS, and Management Interface

Prototype Implementation

Hardware

The prototype design of the Departure Planner interface has been implemented using Compaq iPAQ PDAs for the Portable Electronic FPSs and a desktop computer for the management interface. The iPAQs communicate with the management interface via a RF wireless local area network. The PDAs are not considered appropriate for a production system. However, they have a number of attributes which are useful for prototyping the Portable Electronic FPS design: they reasonably approximate the size of paper strips, they have a straightforward software development environment, they have a touch-screen for direct input, and it is easy to add wireless networking capability to the PDAs. With the growth of handheld computer technology, it is assumed that devices will be available for a production Portable Electronic FPS system which will have greater functionality than currently available devices, lower costs, and a form factor customized for this application.

Management Interface Display

The prototype management interface consists of runway, taxi, and pushback virtual queues, displayed in a timeline format similar to that used by the NASA Traffic Management Advisor, a DST for sequencing and spacing arrival traffic [9]. This format is chosen to make the management interface compatible with arrival DST interfaces, given that departure operations are often dependent on arrivals and a single runway may be used for both arrival and departure traffic.

The interface also displays an airport surface map, as shown in Figure 7. This could be used to increase interactivity between the Portable Electronic FPSs and the management interface (e.g., when a flight strip is picked up by a controller, that aircraft is highlighted on the surface map). Provisions are also made to input downstream constraints and the current runway configuration. The management interface could also include interfaces to weather data and departure performance metrics as further possibilities.

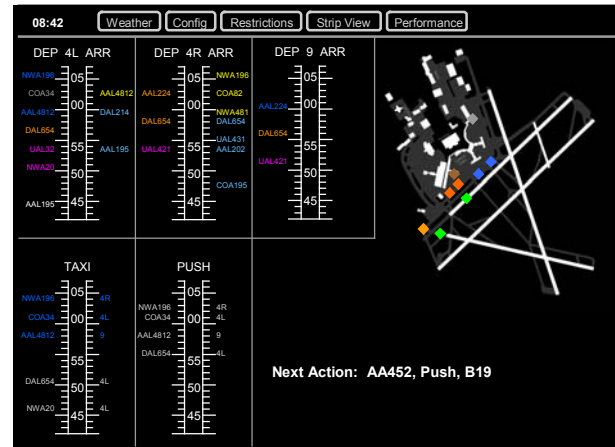


Figure 7. Management Interface Example Display

Portable Electronic FPS Display

The Portable Electronic FPS display shows the information contained on paper strips and supports the functionality required for the Departure Planner. Because the FPS is well-suited to showing an aircraft-centric view of the departure process, Departure Planner advisories are also included on the Portable Electronic FPS. These advisories are displayed in the form of a tabular event listing for a particular aircraft, instead of timelines organized by airport resource as they are shown on the management interface. The events consist of the major state changes or control points that the aircraft will transition through during its departure: calling ready for gate pushback, pushback clearance, taxi clearance, and takeoff clearance. The timing and sequence of the aircraft events is displayed, along with restrictions on these events (e.g., miles-in-trail, ground delay program, waiting for another aircraft to push).

This leads to the general layout of the Portable Electronic FPS shown in Figure 8. The traditional elements of the paper FPS – call sign, navigation equipage, route, heading, and altitude blocks – are located along the top of the display. The bottom half of the display contains the tabular aircraft event listing and soft buttons for recording clearances. In addition, it has been noted that an important attribute of the paper FPS is the ability to make free annotations [5]. For this purpose, a scratchpad area is included in the upper-right corner of the display

where the controller can make annotations that do not need to be interpreted by the system.

CALLSIGN	GATE	TAXIPATH / HOLD PT.			Scratchpad
TYPE/EQUIP	RWY	HDG	ALT1	ALT2	
SQUAWK	ROUTE				
	ROUTE				
Event	Time/Seq	Wait For	Action		
Aircraft events, time and sequence of event, and what must occur before event					Clearance Buttons
CURRENT TIME		Misc. Control Buttons			

Figure 8. Portable Electronic FPS Layout

An example of this layout is shown in Figure 9. This aircraft has already called ready for pushback and is now waiting for pushback clearance. The event listing shows that the Departure Planner advises the aircraft is number two for pushback, and should wait for another aircraft (AAL195) to push first.

DAL306	B19				
H/B763/E	17L	240	---	FL370	
5177	DFW DALL6 EIC HRV J58 COVIA PIE MINNEE3 MCO				
Event	Time/Seq	Wait For	Action		
ReadyPush	10:17		Push		
Push	10:22 / #2	AAL195			
Taxi	10:25 / #5	UAL260			
Takeoff	10:28 / #8	MIT: EIC 20			
	10:21		Undo		

Figure 9. Portable Electronic FPS Display for Aircraft Awaiting Pushback Clearance

Controller Interaction with Portable Electronic FPS and Management Interface

Controller interaction with the Portable Electronic FPS consists of modifying the flight data fields, issuing clearances, and writing free annotations. While it is desirable to replicate the interaction mechanisms of the paper flight strips as

closely as possible, this presents problems for the modification of flight data fields. With the paper FPS, changes are made by writing directly on the strip to indicate the new value. Handwriting recognition approaches were considered as an input modality for the Portable Electronic FPS but were rejected in favor of a menu-based approach (shown in Figure 10) due to the verification workload associated with handwriting recognition.

The menu approach was considered appropriate since most of the expected data fields have a discreet number of possible values which can be conditionally determined. For example, to change an assigned runway (if the Departure Planner selection was unacceptable) the controller would first tap the runway data field, which would then be highlighted. Soft buttons for each possible runway would then appear in the lower half of the screen. A new runway is chosen by tapping on the appropriate button. This change can then be confirmed by tapping the accept button or cancelled by tapping the cancel button with the stylus.

Free annotations are done by writing with the iPAQ stylus on the touch-screen. Clearances are issued by tapping soft clearance buttons with the stylus. These buttons change depending on the aircraft's departure state. For example, an aircraft waiting for taxi clearance would have buttons for taxi clearance to the runway, taxi clearance to an intermediate hold short point, and a button to indicate that the aircraft has received the current airport weather information (ATIS). For an aircraft in sequence at the runway threshold, the Portable Electronic FPS would show buttons for position-and-hold clearance and takeoff clearance.

The clearance buttons are color-coded. Yellow indicates that the aircraft is not yet first in sequence for that event. Green indicates that the aircraft is first in the sequence. In the event of an incorrect or inadvertent clearance being recorded by the controller on the FPS, an undo button is provided to return the aircraft to its last state. Because the time a clearance is issued can be automatically recorded by the Portable Electronic FPS, the clearance buttons replace the need for the controller to write down the ready for pushback and departure times as is currently done with paper strips.



Figure 10. Changing Assigned Runway with Menu-Based Input

Initial controller interaction with the management interface consists of resequencing actions, which are performed via drag-and-drop operations on the timelines, and choosing runway configurations via a menu-based interface.

Preliminary Design Evaluation

Initial feedback on the prototype system has been received from air traffic controllers in the Boston area. The use of soft buttons to record clearances instead of writing clearance times was viewed as the most desirable new functionality of the Portable Electronic FPS. It was also noted by a Boston TRACON controller that an electronic FPS could replace the existing interface between tower and TRACON controllers at Boston Logan airport. Currently, a video camera is used to show TRACON controllers an image of the flight strips which will soon be transferred to their control from the tower. The utility of this system is reduced by changing lighting conditions. With an electronic FPS system, the TRACON controllers could have their own interface showing flights that are about to come under their control.

Further input will be solicited from tower controllers to improve the prototype interface design, especially with regard to the departure planner elements of the displays. In particular, it is desired to know if absolute or relative timing information is more useful for the tabular aircraft events list on the Portable Electronic FPS. Also, the most important information to show for each

type of restriction (MINIT, MIT, DSP, APPREQ, EDCT, etc.) is unknown at this time and will be determined through controller evaluations.

Once the prototype interface design has been refined based on controller input, subjective and objective evaluations of the functional viability of the Portable Electronic FPS concept will be conducted. Of particular interest is whether or not the Portable Electronic FPS system better satisfies the human factors requirements of the control tower, or if a fixed, head-down display would suffice.

Such testing will begin with a simple experiment in which controllers will perform actions on the Portable Electronic FPS, a fixed electronic FPS, or a paper FPS while simultaneously performing another task which requires head-up observation. Further goals are to conduct simulation studies and field trials, possibly using a control tower simulator such as the NASA Future Flight Central facility.

Conclusions

With the advances in handheld computer and wireless communication technology, a new approach to air traffic control DST interfaces has been enabled, particularly for use in an airport control tower. This approach has been prototyped using PDAs and a wireless local area network to create an interface in the form of a Portable Electronic FPS. The Portable Electronic FPS combines the benefits of a paper FPS with the advantages of an electronic FPS. A departure DST is used as a motivating example for the Portable Electronic FPS system. Initial controller reaction to the interface has been favorable, although more testing and evaluation must be completed to determine the viability of the Portable Electronic FPS concept.

Acknowledgements

This research is supported by NASA grant NCC 2-1147. The authors would also like to thank Steve Atkins and Deborah Walton at NASA Ames, and Boston TRACON controllers for their input.

References

- [1] Nolan, Michael S., 1999, *Fundamentals of Air Traffic Control*, Third Edition, Pacific Grove, CA, Brooks/Cole, pp. 217-222.
- [2] Mertz, Christophe, Stephane Chatty, Jean-Luc Vinot, 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, <http://atm-seminar-2000.eurocontrol.fr/acceptedpapers/pdf/paper106.pdf>
- [3] 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.
- [4] Sellen, Abigail J., Richard H.R. Harper, 2002, *The Myth of the Paperless Office*, Cambridge, MA, MIT Press, p. 114
- [5] 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, <http://atm2001.eurocontrol.fr/finalpapers/pap87.pdf>
- [6] Mackay, Wendy E., Anne-Laure Fayard, Laurent Frobert, Lionel Medini, 1998, "Reinventing the Familiar: Exploring an Augmented Reality Design Space for Air Traffic Control", *Conference Proceedings on Human Factors in Computing Systems*, New York, NY, ACM Press, pp. 558-565.
- [7] Anagnostakis, Ioannis, Husni R. Idris, John-Paul Clarke, Eric Feron, R. John Hansman, Amedeo R. Odoni, William D. Hall, 2000, "Conceptual Design of A Departure Planner Decision Aid", 3rd USA/Europe Air Traffic Management R&D Seminar, <http://atm-seminar-2000.eurocontrol.fr/acceptedpapers/pdf/paper68.pdf>
- [8] U.S. DOT, 1995, *BOS TWR 7110.11D: Boston ATCT Standard Operating Procedures*
- [9] Hoang, Ty, Harry N. Swenson, 1997, "The Challenges of Field Testing the Traffic Management Advisor (TMA) in an Operational Air Traffic Control Facility", NASA TM-112211, http://atrs.arc.nasa.gov/atrs/97/hoang/977300/977300_hoang.pdf