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Electronic Flight Data in Airport Traffic Control Towers: Literature Review

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Technical Report

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16. Abstract

The Federal Aviation Administration (FAA) is investigating the potential effects of implementing electronic flight data systems (EFDSs) at Airport Traffic Control Towers (ATCTs). This literature review examines task analyses, published literature, and recent field observation data to explore the basic functionality of flight progress strips (FPSs) in the ATCT. The author identifies gaps in the research and searches for general principles to guide the design of an EFDS prototype. Given the proper design of the interface and automation, an EFDS should maintain some of the basic functionality and benefits of the FPSs, reduce workload related to flight data entry, tracking and sharing, and provide new features that will enhance controller performance and encourage use. The author presents possible risks and outcomes that may accompany an EFDS in FAA ATCTs.

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Executive Summary

Given the Federal Aviation Administration's (FAA) predicted increase in the number of airport traffic control tower (ATCT) operations from 62.7 million in 2003, to 70 million in 2007, the author of this report is investigating the potential effects of implementing electronic flight data systems (EFDSs). The historical artifact of paper flight progress strips (FPS) inherently limits the usefulness of flight data. However, with an EFDS, there is the potential for controllers to acquire, record, and track flight data more efficiently. An EFDS may potentially improve controllers' ability to communicate and share flight data with others, and provide new tools to support controller decision making.

There is a great deal of variability among the 449 ATCTs in the United States. Each ATCT provides different types of services, different types of supporting equipment, and different standard operating procedures based on airport configuration and the number and type of controller positions present. While the presence and use of FPSs is common among ATCTs, the ways in which controllers use flight data among these various facilities is not. The variability between ATCTs poses a significant challenge for the design of an EFDS and we must understand how controllers use flight data in different types of ATCTs. It is likely that no single EFDS solution will be optimal for all ATCTs.

We must also consider how best to preserve the current benefits afforded by FPSs when designing an EFDS. There is a good deal of debate in the literature regarding the usefulness of FPSs. This debate has typically centered on the en route domain of air traffic control without considering other domains such as the ATCT. Researchers must ask and answer the same types of questions about the ATCT domain as they did in the en route domain, because these are fundamentally different tasks with different cognitive requirements and different interactions with flight data. To date, researchers have conducted very little work in the ATCT domain and it would serve the FAA well to close this gap in our understanding of how controllers operate in the ATCT. The goal of our research is to close this knowledge gap and eventually design optimal solutions for the use of EFD in ATCTs.

1. Introduction

Airport operations, logged by controllers in the 449 Federal Aviation Administration (FAA) airport traffic control towers (ATCTs), were projected to increase from 62.7 million in 2003, to 70 million in 2007 (FAA, 2004a). In anticipation of the increase in air traffic, the FAA is investigating the potential effects of implementing an electronic flight data system (EFDS) in ATCTs. The EFDS would replace the paper flight progress strips (FPSs) that controllers currently use. FPSs inherently limit the usefulness of flight data because controllers must manually update the information contained on them. Controllers also must physically pass FPSs from one controller to another within the ATCT. These inherent limitations also restrict the controllers' ability to communicate flight data information with other facilities such as the Terminal Radar Approach Control (TRACON) and Air Route Traffic Control Center (ARTCC). Currently, controllers must perform most communication and coordination between the ATCT and other facilities via landline.

One primary interest is how to preserve the current benefits of FPSs while enhancing the performance of air traffic controllers and the National Airspace System (NAS). To do so, we must understand the similarities and differences among ATCTs as well as all of the tasks involving FPSs, flight data, and the communication of information among air traffic controllers. Researchers can contribute to the success of an EFDS if they address some major gaps in the existing research by developing a better understanding of the actual cognitive benefits afforded by FPSs. System designers must preserve or enhance these benefits with an EFDS. Researchers must also address long-standing organizational norms during the design process to ease the transition from FPSs to an EFDS.

2. The ATCT Environment

Among the 449 ATCTs in the United States, each provides a particular type of service including visual flight rules only, non-radar, or radar approach control. Within each ATCT, there are different types of equipment, specific controller positions, and duties that vary by facility. FAA Order 7110.65P, Air Traffic Control (FAA, 2004b) defines the responsibilities of controllers and the procedures they use. However, in addition to FAA Order 7110.65P, each ATCT typically has its own facility directive that provides a set of supplemental standard operating procedures to address local idiosyncrasies. These facility directives are necessary to account for the wide variety of airport and airspace configurations and the variety of air traffic that use the airports and surrounding airspace.

Because of the variety of ATCT configurations and operations at each airport, each ATCT has their own particular staffing needs. Some ATCTs may operate quite well with just one controller on duty, while others may require seven or more controllers to safely handle all of the aircraft. The controller positions in an ATCT include Local Control (LC) and Ground Control (GC). These positions are in direct communication with the aircraft. They ensure that aircraft remain separated within their area of responsibility including both airspace and the airport surface. An ATCT may also staff a Tower Associate position, also called "Local Assist," "Ground Assist," "Local Associate," or "Ground Associate," and/or a Tower Cab Coordinator position, also referred to simply as "Coordinator." Two other common positions in the ATCT are Flight Data (FD) and Clearance Delivery (CD). The CD position is sometimes referred to only as "Clearance." ATCTs often combine the FD and CD positions (FD/CD) during periods of lower taskload. Some ATCTs staff multiple GC and LC positions in order to handle large volumes of aircraft. For example, one LC position may handle arriving aircraft while a second LC position handles departing aircraft.

Each controller position has a general set of duties as defined in FAA Order 7110.65P (FAA, 2004b). The tower positions of LC and GC ensure aircraft and vehicle separation, initiate control instructions, monitor and operate communications equipment, use the tower radar display(s), assist the Tower Associate position with coordination, visually scan the tower cab environment, ensure that computer entries are completed, ensure that FPS marking is completed, and process and forward flight plan information. The GC position provides aircraft and vehicle taxi instructions to and from the airport movement area and the ramp and gate area, coordinates crossing or use of active runways, and determines the departure sequence. The LC position provides departure and arrival sequencing and spacing by issuing clearances to all aircraft in the airport traffic area and all aircraft and vehicles on the active runways. Both the GC and LC positions may be required to coordinate among multiple other LC and GC positions.

The general duties of the Tower Associate are to ensure separation, operate interphones (landlines), maintain awareness of activity in the tower cab, and use the tower radar display(s). The Tower Associate also assists the other tower positions by accepting or initiating coordination, managing flight plan information, and ensuring that computer entries and FPS marking are completed.

It is the general duty of the Tower Coordinator to coordinate traffic actions among facilities and positions and to advise the Tower Associate(s) of relevant actions needed to accomplish overall goals. The Tower Coordinator relieves the other tower positions (LC and GC) of traffic flow management duties.

The FD position operates interphones, processes and forwards flight plan information, compiles statistical data such as traffic counts and delay times, and observes and reports weather information. The CD position operates communications equipment, processes and forwards flight plan information, issues clearances to pilots, and ensures the accuracy of pilot read backs.

Even though each controller position has a generally defined set of functions, these functions may become intermingled as staffing levels change and as controllers share responsibilities. According to the team concept as stated in FAA Order 7210.3T, Facility Operations and Administration, and in FAA Order 7110.65P, Air Traffic Control (ATC), “There are no absolute divisions of responsibilities regarding position operations. The tasks to be completed remain the same whether one, two, or three people are working positions with a tower cab/facility/sector. The team as a whole, has responsibility for the safe and efficient operation of the tower cab/facility/sector.” (Section 10-1-2a, FAA, 2004c; Section 2-10-3a, FAA, 2004b). Therefore, even though there are a generally defined set of duties for each ATCT position, all of the ATCT positions must cooperate, share duties as needed, and perform any additional duties that will assist in meeting the goals of the team.

3. How Controllers Use FPSs in the ATCT

Even though there is substantial variability among ATCTs, the use of FPSs is relatively ubiquitous. In addition to FPSs, controllers use other sources of information along with tools for communication, coordination, information organization, and decision making. However, one of the arguably central tools used in the ATCT along with the radio is the FPS (Bruce, 1996).

Perhaps it is not surprising that the FPS has become a cornerstone of the ATC task. The use of FPSs has a long history, and since their inception in the 1930's and 1940's, very little has changed (Vortac et al., 1996). Over time, the FAA has rooted the use of FPS through training regimens, handbooks, standard operating procedures, and facility directives. There is currently a significant amount of pressure exerted upon controllers and facility managers to use FPSs (Durso & Manning, 2002). The pressure to use FPSs arises from established training and evaluation criteria, official documentation on the use of FPS in FAA Order 7110.65P, Air Traffic Control (FAA, 2004b), facility standard operating procedures, facility directives, and the need for FPSs to sometimes serve as a legal document of clearances that a controller issued. Because the use of FPSs and the information they contain has become an integral part of the ATCT task, it is important to understand how controllers use FPSs in the ATCT domain and how the FPSs aid in the flow of information. Acknowledging differences among ATCTs, the general flow of information for departure aircraft is from FD/CD to GC to LC. The LC position then transfers responsibility and necessary information to the TRACON. For arrival aircraft, the information moves in the opposite direction from the TRACON to LC to GC. The FD/CD position is not concerned with arrival aircraft.

The type of information that controllers pass among each another varies too depending on the phase of an aircraft's flight (FAA, 2004b). Figure 1 shows the general format for a FPS used in an ATCT. The actual dimensions of a FPS for use in the ATCT are 7/16" x 6 7/16". In the figure, the numbered fields identify the information blocks on the FPS.

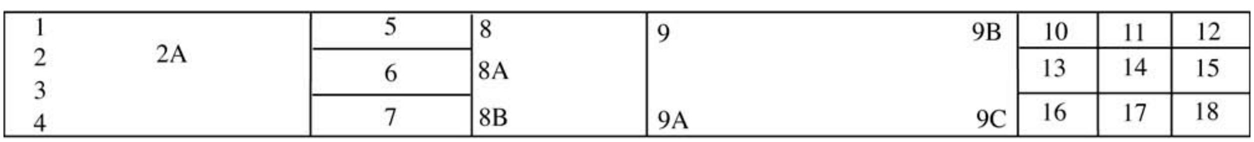

Figure 1. Terminal FPS with numbered fields to identify the information blocks. Note: The numbers shown in this figure do not appear on an actual FPS.

Information recorded on the FPSs (FAA Forms 7230-7.1, 7230-7.2, and 7230-8) are entered in the corresponding numbered spaces. Tables 1, 2, and 3 describe the information that occupies each block of an arrival, departure, and overflight FPS, respectively.

Table 1. Information Recorded in Each Block of the Arrival FPS
(reproduced from FAA Order 7110.65P)

Block	Information Recorded
1.	Aircraft identification.
2.	Revision number (FDIO locations only).
2A.	Strip request originator. (At FDIO locations this indicates the sector or position that requested a strip be printed.)
3.	Number of aircraft if more than one, heavy aircraft indicator "H/" if appropriate, type of aircraft, and aircraft equipment suffix.
4.	Computer identification number if required.
5.	Secondary radar (beacon) code assigned.
6.	(FDIO Locations.) The previous fix will be printed. (Non-FDIO Locations.) Use of the inbound airway. This function is restricted to facilities where flight data is received via interphone when agreed upon by the center and terminal facilities.
7.	Coordination fix.
8.	Estimated time of arrival at the coordination fix or destination airport.
8A.	**OPTIONAL USE**.
8B.	**OPTIONAL USE**, when voice recorders are operational; **REQUIRED USE**, when the voice recorders are not operating and strips are being used at the facility. This space is used to record reported RA events when the voice recorders are not operational and strips are being used at the facility. The letters RA followed by a climb or descent arrow (if the climb or descent action is reported) and the time (hhmm) the event is reported.
9.	Altitude (in hundreds of feet) and remarks.
NOTE	*Altitude information may be written in thousands of feet provided the procedure is authorized by the facility manager and is defined in a facility directive, i. e., FL 230 as 23, 5,000 feet as 5, and 2,800 as 2.8.*
9A.	Minimum fuel, destination airport/point out/radar vector/speed adjustment information. Air Traffic managers may authorize in a facility directive the omission of any of these items, **except minimum fuel,** if no misunderstanding will result.
NOTE	*Authorized omissions and optional use of spaces shall be specified in the facility directive concerning strip marking procedures.*
9B.	**OPTIONAL USE**.
9C.	**OPTIONAL USE**.
10-18.	Enter data as specified by a facility directive. Radar facility personnel need not enter data in these spaces except when nonradar procedures are used or when radio recording equipment is inoperative.

Note: Flight Data Input/Output (FDIO), Resolution Advisory (RA)

Table 2. Information Recorded in Each Block of the Departure FPS (reproduced from FAA Order 7110.65P)

Block	Information Recorded
1.	Aircraft identification.
2.	Revision number (FDIO locations only).
2A.	Strip request originator. (At FDIO locations this indicates the sector or position that requested a strip be printed.)
3.	Number of aircraft if more than one, heavy aircraft indicator "H/" if appropriate, type of aircraft, and aircraft equipment suffix.
4.	Computer identification number if required.
5.	Secondary radar (beacon) code assigned.
6.	Proposed departure time.
7.	Requested altitude.
NOTE	*Altitude information may be written in thousands of feet provided the procedure is authorized by the facility manager, and is defined in a facility directive, i. e., FL 230 as 23, 5,000 feet as 5, and 2,800 as 2.8.*
8.	Departure airport.
8A.	**OPTIONAL USE**.
8B.	**OPTIONAL USE**, when voice recorders are operational; **REQUIRED USE**, when the voice recorders are not operating and strips are being used at the facility. This space is used to record reported RA events when the voice recorders are not operational and strips are being used at the facility. The letters RA followed by a climb or descent arrow (if the climb or descent action is reported) and the time (hhmm) the event is reported.
9.	**Computer-generated:** Route, destination, and remarks. Manually enter altitude/altitude restrictions in the order flown, if appropriate, and remarks.
	Hand-prepared: Clearance limit, route, altitude/altitude restrictions in the order flown, if appropriate, and remarks.
NOTE	*Altitude information may be written in thousands of feet provided the procedure is authorized by the facility manager, and is defined in a facility directive, i. e., FL 230 as 23, 5,000 feet as 5, and 2,800 as 2.8.*
9A.	**OPTIONAL USE**.
9B.	**OPTIONAL USE**.
9C.	**OPTIONAL USE**.
10-18.	Enter data as specified by a facility directive. Items, such as departure time, runway used for takeoff, check marks to indicate information forwarded or relayed, may be entered in these spaces.

Table 3. Information Recorded in Each Block of the Overflight FPS
(reproduced from FAA Order 7110.65P)

Block	Information Recorded
1.	Aircraft identification.
2.	Revision number (FDIO locations only).
2A.	Strip request originator. (At FDIO locations this indicates the sector or position that requested a strip be printed.)
3.	Number of aircraft if more than one, heavy aircraft indicator "H/" if appropriate, type of aircraft, and aircraft equipment suffix.
4.	Computer identification number if required.
5.	Secondary radar (beacon) code assigned.
6.	Coordination fix.
7.	Overflight coordination indicator (FDIO locations only).
NOTE-	*The overflight coordination indicator identifies the facility to which flight data has been forwarded.*
8.	Estimated time of arrival at the coordination fix.
8A.	**OPTIONAL USE**.
8B.	**OPTIONAL USE**, when voice recorders are operational; **REQUIRED USE**, when the voice recorders are not operating and strips are being used at the facility. This space is used to record reported RA events when the voice recorders are not operational and strips are being used at the facility. The letters RA followed by a climb or descent arrow (if the climb or descent action is reported) and the time (hhmm) the event is reported.
9.	Altitude and route of flight through the terminal area.
NOTE	*Altitude information may be written in thousands of feet provided the procedure is authorized by the facility manager, and is defined in a facility directive, i. e., FL 230 as 23, 5,000 feet as 5, and 2,800 as 2.8.*
9A.	**OPTIONAL USE**.
9B.	**OPTIONAL USE**.
9C.	**OPTIONAL USE**.
10-18.	Enter data as specified by a facility directive.

For arrival, departure, and overflight FPSs, facility managers have the authority to permit omissions and/or optional use of spaces 2A, 8A, 8B, 9A, 9B, 9C, and 10-18, if no misunderstanding will result. However, a facility directive must specify these omissions and/or optional uses. A national standard for spaces 10 through 18 is not feasible due to the differences among local and regional operating methods.

The local and regional differences among ATCTs and individual controllers also reflect in the functions that FPSs serve. While controllers amend the FPSs using a standard set of symbols in accordance with FAA Order 7110.65P (FAA, 2004b) and a few unique markings as published in their own facility directive, there are also individual preferences and styles for using FPSs. For example, some controllers may prefer to stack the FPSs in a bay while others prefer to place the

FPSs in front of them on the desktop. Some controllers may prefer to highlight a certain piece of information on the FPS. Some controllers may sort the FPS by arrival or departure time, while others may sort the FPSs by departure or arrival waypoints. The individual needs of ATCTs and controllers are important, but it is not yet necessary to understand how every one conducts operations in particular. We must first review the existing literature to assess our current level of knowledge about FPSs and their benefits for ATCT specialists. We must identify critical gaps in the research. Then we must collect empirical evidence to bridge any gaps in our understanding about the critical functions of FPSs and how to best support those functions with an EFDS.

4. Debating the Cognitive Role of FPSs

It is clear that controllers use the FPSs and their associated markings for a variety of purposes. A number of researchers have examined the particular functions of FPSs, whereas others have examined the higher-level cognitive processes that controllers support with FPSs. All of these researchers have shown that across various ATC domains controllers use FPSs for workload management (Dattel, Johnson, Durso, Hackworth & Manning, 2005; Durso & Manning, 2002; Gronlund, Dougherty, Durso, Canning & Mills, 2001), memory aids (Buisson & Jestin, 2001; Cardosi, 1999; Dattel et al.; Durso & Manning; Gronlund et al.; Hopkin, 1988; Pavet, 2001; Stein, 1991; Stein & Bailey, 1989, 1994; Zingale, Gromelski, Ahmed, & Stein, 1993; Zingale, Gromelski, & Stein, 1992), facilitating communication and coordination (Berndtsson & Normark, 1999; Buisson & Jestin; Dattel et al.; Durso & Manning; Gronlund et al.; Pavet), cognitive information organization (Dattel et al; Durso & Manning), and planning (Cardosi; Dattel et al.; Gronlund et al.; Pavet; Zingale et al., 1992, 1993). However, researchers have debated the necessity of FPSs and their use.

A primary debate among researchers has centered on whether or not the FPSs provide any real benefit to memory, situation awareness, and ultimately, performance. At the center of the debate are two competing hypotheses: the Interaction hypothesis and the Cognitive Resource hypothesis. The Interaction hypothesis states that the physical interaction with the FPSs is necessary to support cognitive functions such as memory and situation awareness. In contrast, the Cognitive Resource hypothesis views FPS activity as a secondary task that could be automated, at least in part, to free cognitive resources for primary tasks such as ensuring aircraft separation. Researchers have derived these hypotheses based on differing viewpoints regarding the potential effects of automation. With the introduction of electronic flight data (EFD), the potential to automate various related activities becomes a reality. The Interaction hypothesis predicts a decline in overall controller performance, especially in terms of memory and situation awareness, as a result of reducing or eliminating (i.e., automating) the controllers' interaction with flight data (e.g., Garland & Hopkin, 1994; Hopkin, 1995).

In support of the Interaction hypothesis, Garland and Hopkin (1994) argue that controllers cannot passively sustain awareness. Rather, they suggest that active involvement is essential for controllers to be able to exercise their responsibilities and respond to emergency situations. These authors argue for a direct manipulation environment that they believe is essential to maintain and potentially enhance the controller's situation awareness. Furthermore, they state that if automation discards traditional methods and skills, then the ATC system may become both less efficient and less acceptable to controllers. Garland and Hopkin believe that we should not implement automation simply to reduce workload. Removing some functions would leave the controller to process less information or the same information at less depth. Although we could take measures to prevent it, controller skill could dramatically degrade with the use of automation while the system would disguise the developing incompetence and inadequacy. Likewise, Hopkin (1995) predicts that the current direction of the ATC program including the development of data link, decision aids, strategic planning, reduction in workload for reasons other than loss of situation awareness, and EFD will reduce the controller's situation awareness (i.e., the controller's dynamic mental picture of the ATC situation).

In contrast to the Interaction hypothesis, the Cognitive Resource hypothesis predicts an increase in overall controller performance as a result of shedding superficial "housekeeping" tasks. By eliminating or reducing some FPS activity, especially redundant actions or those regarding the superficial management of FPSs, controllers will have more cognitive resources to devote to the primary ATC task of safe and expeditious movement of aircraft (e.g., Albright, Truitt, Barile, Vortac, & Manning, 1994; Truitt, Durso, Crutchfield, Moertl, & Manning, 2000; Vortac et al., 1996). The Cognitive Resource hypothesis does not claim that memory and situation awareness are unimportant for the ATC task, only that the cognitive benefits claimed by the Interaction hypothesis have been overestimated. To date, empirical tests of these competing hypotheses have tended to support the Cognitive Resource hypothesis, particularly in the en route domain. In the extensive series of en route studies conducted by Vortac and their colleagues, limiting interaction with the FPSs did not tend to have a detrimental effect on controller performance. Instead, controllers demonstrated improvements in prospective memory and tended to increase the time they spent attending to the dynamic aircraft representations presented on the radar display (e.g., Albright et al.; Vortac, Edwards, Fuller, & Manning, 1993).

Compared to the en route domain, there is a limited amount of research in the terminal domain which has been less than conclusive. Zingale et al. (1993) conducted a study with eight TRACON controllers who controlled traffic in a medium-fidelity simulation. They found no differences in memory or situation awareness performance between conditions where the controllers annotated FPSs compared to when the controllers did not annotate FPSs. In fact, Zingale et al. reported that video game experience tended to predict the dependent measures of memory and situation awareness, as opposed to whether or not the controllers interacted with the FPSs. These findings do not provide direct support for either the Cognitive Resource or the Interaction hypotheses. However, the findings generally tend to discredit the Interaction hypothesis.

5. Cognitive Functions of FPSs in the ATCT Domain

While the tests of the Interaction and Cognitive Resource hypotheses are interesting and informative, researchers have not conducted these types of experiments in the ATCT domain. Therefore, prior studies are of limited use in understanding how interacting with flight data may affect controllers in the ATCT. It is difficult to generalize prior research to the ATCT domain because the tasks of ARTCC, TRACON, and ATCT controllers differ in a number of respects, especially in terms of memory requirements. Both ARTCC and TRACON controllers must handle individual aircraft for longer durations than controllers in an ATCT. It may take an aircraft 15 or 20 minutes to traverse en route or terminal airspace, whereas controllers in the ATCT only deal with each aircraft for a few minutes. Therefore, the memory requirements for ATCT controllers may be considerably less than for controllers in other domains. Because the tasks of the ATCT controller differ in many ways from the en route and terminal domains, it is appropriate not to generalize past research from the ARTCC and TRACON domains, but rather to ask and answer the same questions in the ATCT domain.

While researchers have conducted a number of studies primarily in the en route domain, the debate between the Interaction and Cognitive Resource hypotheses is just beginning to arise in the ATCT domain. In fact, researchers have conducted only a few studies to understand what controllers are doing in the ATCT and how they are doing it. Recently, Cardosi and Yost (2001) examined controller and pilot errors in airport operations. They reviewed a number of articles including a National Transportation Safety Board (NTSB) special investigation report from 1986 (NTSB/SIR-86/01 as cited in Cardosi & Yost, 2001). That report examined 26 runway incursions and attributed 65% of the incursions to controller error. In 44% of those errors, controllers had forgotten about an aircraft or prior coordination with other controllers. Typically, the controllers failed to remember significant information such as the presence of an aircraft on the runway, a runway closure, or a prior clearance that they had issued. The 1986 NTSB report identified the primary controller-related factors in runway incursions as forgetting aircraft and poor coordination between controllers.

Unfortunately, a dramatic illustration of the 1986 NTSB report findings occurred on March 9, 2000, at Sarasota Bradenton International Airport (SRQ), Sarasota, Florida when four people perished in an aircraft collision on Runway 14. Here is the NTSB synopsis of the accident (NTSB Identification: MIA00FA103A).

NTSB Identification: **MIA00FA103A**
14 CFR Part 91: General Aviation
Accident occurred Thursday, March 09, 2000 in SARASOTA, FL
Probable Cause Approval Date: 5/4/2001
Injuries: 4 Fatal.

At 1024:46, the pilot of N89827 called the Sarasota Bradenton International Airport (SRQ), Sarasota, Florida, ground control/clearance delivery controller (GC) requesting a visual flight rules departure. N89827 originated at the Dolphin Aviation ramp, which is located on the south side of SRQ. At 1025:24, the SRQ GC instructed N89827 to 'taxi to runway [14].' Taxiway A, which is adjacent to the Dolphin Aviation ramp, runs parallel to runway 14 and joins it at the end. N89827 proceeded to runway 14 via taxiway A. As the GC issued the taxi instructions to N89827, he was relieved by the supervisor/ground controller (SGC). The GC provided a relief briefing to the SGC and left the tower cab. At 1028:03, the pilot of N79960 transmitted to ground control that he was 'at [J]ones and ready to taxi.' The Jones Aviation ramp is on the north side of SRQ; aircraft originating at the Jones Aviation ramp intending to use runway 14 are normally assigned intersection departures from taxiway F. The Aeronautical Information Manual, Pilot/Controller Glossary, defines an intersection departure as 'a departure from any runway intersection except the end of the runway.' (The pilot in the right front seat of N79960 held a pilot certificate issued by the Federal Aviation Administration [FAA]. The pilot in the left front seat held a pilot certificate issued by the Canadian Civil Aviation Authority. Although the investigation could not determine which pilot in N79960 was operating the controls, only the right seat pilot was certified by the FAA; therefore, he was the only pilot on board authorized to act as pilot-in-command. Accordingly, this brief will refer to the right seat pilot as 'the pilot' and the left seat pilot as 'the pilot-rated passenger.') At 1028:45, the SGC cleared N79960 to 'taxi to runway [14].'

N79960 held at the intersection of runway 14 and taxiway F. Although the pilot's reported position at the Jones Aviation ramp would suggest an intersection departure at taxiway F, the SGC annotated the flight progress strip for N79960 to indicate that it would be positioned for takeoff from the approach end of runway 14. The SGC told investigators after the accident that he did not recall N79960 originating at the Jones Aviation ramp and that his issuance of the taxi instructions to runway 14, with no mention of the taxiway F intersection, indicated that he must have thought that the airplane was originating at the Dolphin Aviation ramp. At 1030:42, the pilot of N89827 made his first contact with the local controller (LC), stating that he was 'ready for takeoff.' (About the time of this transmission, another airplane, a Cessna 172, N52553, was positioned behind N89827 on taxiway A waiting for departure.) At 1032:46, the pilot of N79960 made his first contact with the LC, stating, 'we're number two ready for takeoff.' (About the time of this transmission, N79960 was positioned behind another airplane, N5287V, which was on taxiway F waiting for an intersection departure.) At 1033:57, the LC instructed N89827 to 'taxi into position and hold' and stated, 'traffic will depart downfield also.' At 1034:22, the LC cleared N5287V for takeoff from the taxiway F intersection. After N5287V's departure, at 1034:43, the LC cleared N89827 for takeoff from the approach end of runway 14. At 1034:47, the pilot of N89827 acknowledged the takeoff clearance. At 1034:51, the LC instructed N79960 to 'taxi into position and hold' on runway 14, which the pilot acknowledged. About 6 1/2 seconds elapsed between the two pilots' transmissions. According to a postaccident interview with the LC, on the basis of the information in the flight progress strip, he believed that N79960 was positioned for takeoff at the approach end of runway 14. When N89827 began its takeoff roll from the approach end of runway 14, the LC erroneously believed that it was safe to instruct N79960 to taxi onto the runway for departure. Witnesses stated that when N89827 obtained takeoff speed near the 6,000-foot remaining marker (about 200 feet from the collision point), N79960 entered the runway from a taxiway (F) on the left side of the runway. Witnesses further stated that N89827 lifted off and turned to the right in what appeared to be an attempt to avoid a collision with N79960. Witnesses indicated that N89827 appeared to stall and that the left wing dropped to a wings-level attitude. About 15 seconds after N79960's acknowledgement of the taxi-into-position-and-hold clearance, a loud burst of static and an emergency locator transmitter signal can be heard on the air traffic control voice tape. N89827 impacted the top of N79960 on runway 14 at the taxiway F intersection. N89827's propeller contacted N79960's aft cabin roof, inboard wing flaps, and fuel tanks. Upon impact, a fire immediately erupted in N79960's fuel tanks. N79960 flipped inverted over the left wing and nose of N89827, and N89827's propeller separated from the engine. The two airplanes came to rest about 75 feet down the runway from the initial impact point on about a 300-degree heading. N89827 was found inverted on the runway, and N79960 was found inverted on top of N89827.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows:

> The failure of the supervisor/ground controller and the local controller to provide effective separation between the accident airplanes on the runway, resulting in a collision during takeoff. Contributing to the accident was the failure of the pilot and pilot-rated passenger on board N79960 to ensure that the runway was clear of traffic before taxiing onto the runway. Also contributing to the accident was the failure of air traffic control guidance and procedures to incorporate redundant methods of verifying aircraft position for both controllers and pilots.

As shown by the preceding NTSB accident synopsis, controller memory, communication, and coordination are important aspects of the tasks that controllers perform in an ATCT. Bales, Gilligan, and King (1989) and Steinbacher (1991) also examined the causal factors of runway incursions. These studies found that about 34% of runway incursions were due to controllers forgetting about an aircraft, forgetting instructions issued to an aircraft, or failing to remember the traffic or runway situation. Therefore, according to the results of these studies, memory appears to be an important component for ATCT operations, particularly for the prevention of runway incursions. Solutions proposed by Cardosi and Yost (2001) to improve controller memory include the development of electronic FPSs. Beyond the solutions proposed by Cardosi and Yost, the FAA must develop effective ATC procedures and controllers must be trained in the proper use of automation.

Bruce (1996) also conducted relevant research that has contributed to our understanding of controller behavior in the ATCT. Bruce conducted a study to examine the physical performance criteria for ATCT specialists. Her data provided valuable information about what controllers did while working. She collected time, motion, and general activity data from six ATCTs chosen based on traffic volume, type of ATC service, variations in building design, size, and number of staff. The facilities included Austin-Bergstrom International (AUS), Memphis International (MEM), Milwaukee - General Mitchell International (MKE), Philadelphia International (PHL), San Francisco International (SFO), and Teterboro (TEB) airports. The activity frequency counts from her study showed that regardless of which position controllers were working, they most often manipulated FPSs, microphones, and writing pens. Along with their human abilities, these are the controllers' primary tools. Table 4 shows the percentage of interactions that Bruce observed controllers using FPSs by facility and position.

Table 4. Percentage of Controller Interaction with FPSs by Facility and Position and Total Percentage of Activity Accounted for by "Flight Strip" Interactions (Bruce, 1996)

	ATCT Position			
	FD/CD	GC	LC	Total
AUS	20%	17%	13%	16.08%
MKE	20%	17%	7%	15.59%
MEM	24%	16%	14%	17.21%
PHL	27%	31%	25%	27.48%
SFO	19%	25%	22%	22.47%
TEB	22%	26%	18%	20.71%

Bruce also showed that GCs spent almost one-half of their time (6:59/15:00 min) directly observing traffic out of the window, whereas LCs spent only about one-third of their time (5:40/15:00 min) looking outside. She also reported that the LCs' time observing traffic increased significantly (9:27/15:00 min) when radar data were available in the ATCT. These results are interesting in that they suggest, together with the activity data, that controllers are spending much of their time attending to FPS tasks inside the tower cab.

Pavet (2001) found results similar to those of Bruce (1996). Pavet conducted a cognitive analysis of the use of FPSs at South Tower at Paris Charles de Gaulle airfield. Pavet observed controller behavior by using three fixed cameras and one wearable camera placed on the head of controller participants while they worked. Experimenters also recorded voice communications, radar data and flight plan data during the course of one day. Based on the data from the head mounted camera, Pavet found that the controllers' attention was oriented inside the ATCT 80% of the time and outside the ATCT the other 20% of the time. This result suggests that the information that controllers needed the most was inside the ATCT, but the author does not state from which controller position they collected these data. Like Bruce (1996), Pavet also concluded that voice communication and FPSs were central to the ATCT task.

Ammerman, Becker, Bergen, et al. (1987), Ammerman, Becker, Jones, Tobey, and Phillips (1987), and Alexander et al. (1989) conducted an earlier series of studies that contributed to our understanding of the ATCT task. These authors published a comprehensive set of task analyses of ATCT activity, which are still relevant today. Alexander et al. examined the baseline, or current activity, of ATCTs, while Ammerman, Becker, Bergen, et al. explored the future concept of the Tower Control Computer Complex (TCCC) envisioned within the Advanced Automation System concept. As the name implied, the TCCC was to rely more on computer power, shared information, and automation and rely less on pen and paper. Some of the concepts envisioned for the TCCC like Airport Surface Detection Equipment (ASDE) have materialized while others, like reconfigurable tower position consoles at each controller position, have not. Despite the current state of affairs, these task analyses are still valuable today in that they provide, among other things, compositional graphs that show the logical flow of operational tasks, information requirements, and necessary cognitive/sensory attributes.

Only recently have researchers collected data specifically on controllers' FPS activity in the ATCT. Dattel et al. (2005) conducted a study to gather information about how controllers use FPSs in the ATCT by observing FPS movement and marking frequencies. They also conducted structured interviews to determine the controllers' perceived psychological benefits of various FPS markings. Dattel et al. used four subject matter expert observers to record controllers' FPS marking and handling behavior during live operations for the three primary control positions (FD/CD, GC, LC) at ten ATCTs located across the United States. The ATCTs were of various sizes and handled differing levels and complexity of traffic. The ten facilities were Addison Municipal (Level 7), Allegheny County (Level 6), Hartsfield-Jackson Atlanta International (Level 12), Dallas Love Field (Level 9), Los Angeles International (Level 12), Snohomish County/Paine Field (Level 6), DeKalb Peachtree (Level 7), Pittsburg International (Level 11), Seattle-Tacoma International (Level 10), and John Wayne (Level 9). The authors examined both the observed frequency of FPS marking/usage by controller position and facility size and the reported importance of FPS marking. In addition, they followed the observation sessions with questionnaires and 175 directed interviews with 95 different controllers to gain insight about the perceived psychological benefits of FPSs including communications, memory, organization, situation awareness, and workload.

Sixty-seven percent of the controllers that Dattel et al. (2005) observed placed the FPSs on the desktop rather than using a FPS bay. The GCs marked the FPSs 53% of the time and made marks on notepads 38.7% of the time. The LCs clearly preferred marking on notepads using them 66.4% of the time, compared to marking on FPSs only 28% of the time.

Dattel et al. (2005) observed the frequency of 30 different FPS marks and collected ratings of importance for each type of FPS mark. The authors categorized an FPS mark as "important" if it received a rating above 50 on a scale of 1 (never important) to 100 (always important). Table 5 shows the importance rating and observed frequency for each FPS mark. They combined the importance rating with the observed frequency for each type of FPS mark to determine "critical" marks for each controller position and facility size. Dattel et al. report critical marks as those that occurred frequently and received ratings of high importance. Using a median split, the authors categorized an FPS mark as "frequent" if the mark occurred more that once per 40 minutes of observation. They also performed a median split on the importance ratings. Using this method, the authors identified nine critical marks: ACID/Vehicle, ATIS, Runway Assigned, Altitude, Initial Clearance Issued, Flight Plan Route/Destination, Hold Short, Heading, and Beacon Code Assignment.

Table 5. Importance Rating and Observed Frequency for Each Type of FPS Mark
(Dattel et al., 2005)

FPS Mark	Importance Rating (1-100)	Frequency/20 min
Operation Complete	12.44	3.43
Aircraft/Vehicle ID	69.78	3.19
Clearance to Land/Take Off	42.22	1.79
ATIS	59.30	1.62
Gate Assignment/Location	37.30	1.60
Runway Assigned	56.80	1.24
Altitude	65.70	0.89
Initial Clearance	63.89	0.82
Flight Plan Route/Destination	73.00	0.74
Departure Sector	42.67	0.57
Hold Short	55.78	0.55
Times/Updates/Rolling Time	35.56	0.53
Frequency	45.80	0.48
Heading	66.70	0.37
Beacon Code Assignment	61.70	0.29
VFR Strip Created	21.00	0.25
Delay	57.30	0.20
Time in Position & Hold	51.44	0.17
Intersection Departure	77.20	0.14
Communication Transfer	24.00	0.14
Pre-Departure Clearance	37.44	0.04
Weather Information	50.00	0.03
Pattern Traffic	33.89	0.03
Comments/Pilot Request	30.00	0.02
Aircraft Type/Equipment	53.50	0.02
Go Around	29.63	0.02
Pilot Report	33.22	0.01
Emergencies	75.38	0.01
Gate Hold	39.60	0
VFR Flight Following	23.56	0

Dattel et al. (2005) reported that the controllers' use of the nine critical marks differed with position and facility size. The FD/CD position tended to make FPS marks coded as Initial Clearance and Altitude. The FD/CD position made the most Altitude marks at medium and large facilities. The GC position made the most marks coded as Runway Assigned. LCs also made this mark to some extent at large facilities. The FD/CD and GC position both tended to make marks coded as ATIS, Beacon Code, Flight Plan Route/Destination, and Heading. ATIS marks increased with facility sizes. The GC position made most of the Beacon Code marks at small facilities, but FD/CD made most of the marks at large facilities. The FD/CD made Flight Plan Route/Destination marks especially at medium and large facilities and the GC also made this mark at large facilities. Both the FD/CD and GC position made Heading marks, especially in small facilities. Heading marks tended to decrease with facility size. The LC made most of the

ACID/Vehicle marks, but the GC also made this mark. Both the LC and GC tended to make the ACID/Vehicle mark more often as facility size increased. The LC made most of the Hold Short marks. While the LC made some Hold Short marks at large facilities, most of these marks were made at medium size facilities. We advise that the "critical marks" as defined by Dattel et al., be viewed with caution. First, they collected the importance ratings from controllers who were not associated with the observation data. Second, the various control positions were not considered in the importance ratings. Third, there was a wide range of frequency values that Dattel et al. categorized as "high."

Dattel et al. (2005) identified six additional marks that controllers rated as high in importance but occurred infrequently: Delay, Time in Position and Hold, Intersection Departure, Weather, Aircraft Type/Equipment, and Emergencies. They identified six FPS marks that occurred frequently but rated as being of low importance: Operation Complete, Clearance to Land/Take off, Gate Assignment/Location, Departure Sector, Times/Updates/Rolling Time, and Frequency. Finally, the authors identified nine FPS marks that were low in importance and occurred infrequently: VFR Strip Created, Communications Transfer, Pre-Departure Clearance, Pattern Traffic, Comments/Pilot Request, Go Around, PIREP, Gate Hold, and VFR Flight Following.

In addition to frequency and importance ratings, Dattel et al. also attempted to determine the perceived psychological benefits of FPSs. The controllers at each position reported using the FPSs for different reasons, and these uses did not depend on facility size. Controllers at the FD/CD position reported that FPS activity benefited communication, workload, and memory and they used marking primarily for the benefit of others. Marks indicating initial clearance, frequency change, departure sector, and altitude were exclusive to the FD/CD position. Controllers at the GC position reported that FPS activity supported all five psychological functions of communication, memory, organization, situation awareness, and workload. Primarily the controllers at the GC position made marks regarding runway assignment and only the FD/CD and GC positions made marks relating to Air Traffic Information Service (ATIS), gate assignment/location, flight plan route/destination, and heading. Controllers at the LC position reported FPS benefits for memory, organization, and situation awareness. Only controllers at the LC position made marks relating to hold short clearances and clearances to take off or land. Controllers at both the GC and LC positions believed that the primary benefits of FPS were associated with memory and situation awareness. However, researchers have yet to determine whether any of these reported benefits are actual or just perceived, and if they are real, the size and duration of any effect on controllers' performance.

Overall, the existing research on the use of FPSs in ATCTs leaves us with more questions than answers. While it is fairly clear that FPSs are used to communicate and coordinate information, the actual cognitive benefits of FPSs are less than certain. Controllers certainly spend a substantial amount of their time attending to FPSs. They report perceived psychological benefits relating to memory, situation awareness, and workload. However, it appears that controllers can perform some of the tasks with FPSs just as well with a notepad. The predominance of empirical data suggests that the Interaction hypothesis is much less important than providing controllers with the critical information in a timely manner. Thus, automation may assist controllers without degradation of skills or situation awareness. Furthermore, we do not have any empirical data regarding the actual benefits of FPSs and FPS marking beyond self-reports provided by controllers. Researchers must continue to conduct experiments with ATCT controllers to better understand the true cognitive benefits of FPSs and to understand the information that controllers need and how best to deliver it to support the cognitive requirements of the job. They must empirically test the claims of both the Interaction and Cognitive Resource hypotheses. Researchers must also examine any potential negative effects of changing FPS behavior that they discover to determine the duration of any performance decrements and if expert controllers can overcome these decrements in relatively short periods of time.

6. An Alternative to FPSs

Replacing the FPSs used in the ATCT with an EFDS would require new hardware, procedures, and automation that relieve the controller of workload arising from non-essential, "housekeeping" tasks while improving performance. Performance may benefit simply by the appropriate redistribution of the workload associated with FPSs, but properly designed interfaces and automation could elevate performance beyond that which controllers might obtain only by addressing workload. A feasible EFDS in the ATCT should integrate the controller's perceptual abilities with improvements in navigation, radar, and automation including weather detection and traffic alerting systems (Ammerman, Becker, Bergen, et al., 1987). The EFDS should provide the same proven critical benefits as FPS while eliminating outdated uses such as recording of some clearances to establish a legal record. The EFDS, resting on the concept of System Wide Information Management (SWIM) (FAA, 2004d), will provide new functionality through automation, especially in terms of information sharing. Such new functionality should make some current tasks easier and provide controllers with the ability to perform actions that they could not perform with FPSs. New features could conceivably provide more and better information to controllers compared to what is currently available, resulting in better decision making, safety, and efficiency.

There are a number of features that an EFDS could provide in an ATCT. The ability to display and input flight data from a single interface opens many possibilities, but the ability to share information among various systems is what will make an EFDS especially useful. Information will be able to move between a flight data element and any other component of the primary system. Two-way information updates provide easy access and sharing of flight data such as clearance amendments, predicted runway/taxiway incursions, aircraft location on a taxiway, posting and updating expected departure clearance times, alerts for traffic flow restrictions, and wake turbulence warnings. The sharing of information will not only benefit FAA operations, but also the airlines and their decision-making abilities. An EFDS allows for the linking of elements from one or more situation displays so that controllers can emphasize and identify items of interest simultaneously for categorization. Electronic flight data elements can appear only when controllers need them the most and still preserve the ability to access all information about any flight at any time. An EFDS would provide an interface for digital communications such as controller-pilot data link communications (CPDLC). CPDLC via the EFDS interface would allow the controller to provide flight information services (e.g., pilot reports, weather reports, maps, approach plates, etc.), pre-departure clearances, full taxi instructions including gate information and visual depiction of taxi route, digital ATIS, and even landing and takeoff clearances. An EFDS also allows for simplified data input such as recording certain clearances or updating an ATIS code with simple motions or gestures while preserving the ability to make freehand notation. More information will be available to controllers and controllers will be able to share information as necessary. Researchers have already designed automation tools that could potentially be integrated with an EFDS under the SWIM concept. Such tools provide assistance with taxi sequencing (e.g., Departure Planner Decision Aid; Anagnostakis et al., 2000) changing runway configuration (e.g., Surface Management System; Atkins & Brinton, 2002), and digital watermarking (e.g., Hering, Hagmüller & Kubin, 2003; Prinz, Sajatovic, & Hering, 2004).

Beyond the inherent abilities provided by an EFDS, the potential advantages of an EFDS are numerous. An EFDS would eliminate workload associated with placing FPSs in holders, distributing FPSs, and handling multiple FPSs for a single flight. Controllers may increase the time they spend looking out the window of the tower cab and directly observing the traffic situation. Controllers also may increase their awareness of other controllers' actions through the use of both distributed displays that share flight data elements and through the use of shared displays (Mertz & Lecoanet, 1996). Flight data activity that controllers currently tally by time-consuming, manual processes could be automatically tracked by an EFDS to allow for automatic traffic counts and the recording of timing information and clearances. An EFDS simplifies the act of passing flight data among controller positions within the ATCT and between the ATCT, TRACON, ARTCC, and Airline Operations Centers. Electronic flight data allows controllers to pass information virtually rather than having to move away from their control position and physically transfer a FPS. Although there are new technological challenges with an EFDS, those efforts may be offset by eliminating costs associated with paper FPSs, FPS holders, and the maintenance of the thermal printers.

The potential disadvantages of an EFDS are not as obvious as the advantages. There is a need for researchers to learn about the effects that any new system will have on users. If the EFDS does affect controller performance, the extent and direction of change will depend in part on the design of the EFDS and on how the FAA trains controllers to use it. Even if an initial decrement in performance does occur, controllers may be able to overcome changes to their task rather quickly. Unfortunately, there are not any data on the ATCT domain to inform us about the effects of changing the format of flight data or changing the way that controllers interact with it. Previous data suggests that although the new EFDS will not eliminate physical interaction with flight data, it may change the frequency and types of interactions that controllers perform. Such a change in behavior may have positive or negative effects upon controllers' performance, memory, or situation awareness (e.g., Endsley & Rodgers 1996; Garland & Hopkin, 1994; Hopkin, 1988; Hopkin, 1995; Stein & Bailey, 1994; Vortac et al., 1996; Zingale, Gromelski & Stein, 1992). However, researchers must still answer these empirical questions within the ATCT domain.

Another potential disadvantage of an EFDS is that a pen- or gesture-based system may be more difficult to use than paper FPSs, especially at first (Mertz & Vinot, 1999; Mertz, Chatty, & Vinot, 2000b). Data entry will also become more critical as more people share more information with each other (Della Rocco, Manning, & Wing, 1990). Because controllers are using flight data for safety critical functions, data entry errors could potentially result in other, more serious unwanted outcomes. EFDS designers should make data entry as easy as possible and ensure that methods for identifying and correcting errors are available. The transition from FPSs to an EFDS may also impact the controller selection and training process rendering them less useful and in need of modification (Della Rocco et al.).

The FAA recently implemented a policy establishing that no new displays occupy the ATCT except by an explicit waiver process (Associate Administrator for Air Traffic Services (ATS-1), Policy Statement: Display of Operational Data in Terminal ATC Facilities, FAA Memorandum dated February 13, 2003). This "no new glass" policy arose from the numerous systems that the

FAA has already deployed in the ATCT. Not only have these new systems taken up the limited space inside the tower cab, they also operate independently of one another. In other words, the FAA has filled the ATCT with a multitude of non-integrated systems creating a crowding of the physical space, increased maintenance costs, and the inability of systems to cooperate with one another.

Systems integration may be difficult given the FAA's "no new glass" policy and the various levels of traffic and technology at the 449 ATCTs in the United States. It is very likely that different EFDSs will be needed for different types of ATCTs. For example, ATCTs that have ASDE or other types of surface radar displays may be able to take advantage of an existing data source by integrating the flight data with it. The suggestion of integrating flight data with surface radar data is a viable one. Such an approach has already begun at Nav Canada (Keith Penny, personal communication, November 3, 2004). Airports without ASDE could still take advantage of an EFDS, but the optimal presentation of flight data may require a different form. To take full advantage of EFD, FAA researchers must consider deploying alternative perceptual-spatial displays that do not rely on ASDE. There is one certainty about ATCTs; there is a great deal of variation and one solution will not fit well for all.

Buisson and Jestin (2001) made an initial examination of using a handheld personal computer (PC) such as the Ipaq™ to display and interface with EFD. Such a platform is attractive in that it is small and portable like FPSs. The handheld PC also could provide the ability to store and distribute information such as flight data, checklists, detailed instructions, or aeronautical charts. Buisson and Jestin developed a graphical user interface that looked and functioned like a note pad. Their intent was to use the handheld PC in conjunction with a central workstation. Although they did not conduct a formal experiment, these authors found that the relatively small screen made it impossible to display some complex information such as detailed instructions or large charts. In addition to the limits on the overall amount of information that they could show on the screen, they also acknowledged the limits of technology regarding voice and writing recognition. These technical limitations obviously restrict the development of new uses for the handheld PC, especially in ATC applications.

Doble and Hansman (2003) further examined the concept of using handheld PCs to replace FPSs. They present a design and initial evaluation of electronic FPSs that interface with a decision support tool, The Massachusetts Institute of Technology Departure Planner (Anagnostakis et al., 2000). Doble and Hansman's experiment was a part-task simulation that only considered handling departure aircraft at the GC position. They provided the graduate student participants with a two-dimensional "out-the-window" view on a computer monitor. They asked the participants to take a number of actions and decisions that an actual ATCT controller might make while using electronic FPSs. The experimenters portrayed each FPS on a separate handheld PC. They provided several alternative methods for changing altitude and heading assignments as well as issuing clearances for push back, taxi, and takeoff. The authors rejected handwriting recognition because they thought it would unnecessarily increase workload due to the need to verify inputs and because there were only a limited number of possible values that an ATCT controller would need to use. While the student participants reported that they liked the electronic FPSs, the experiment suffered from threats to both internal and external validity. A lengthy set of instructions and significant practice effects compromised the internal validity of the experiment. More importantly, the low level of realism, part-task activity, and lack of actual controllers compromised the external validity of the experiment.

The usefulness of the handheld PC in ATC is limited for a number of reasons. First, as already stated by Buisson and Jestin (2001), the size of the display is a limiting factor. Second, as pointed out by Ryan, van Schyndel, and Kitchin (2003) in their evaluation of a replacement for FPSs at Australian airports, interacting with a handheld PC requires the use of both hands thereby limiting the ability to use binoculars and handheld microphone switches that FAA controllers commonly use. Third, the nature of the handheld PC display limits the ability to easily share flight data information with other controllers unless there are multiple handheld PCs for the same electronic FPS. The screens are small and difficult to see unless the user is looking directly at them. Fourth, handheld PCs are expensive and require constant and reliable battery power to retain information. Fifth, if a controller drops and breaks a handheld PC containing safety critical information, that information is likely to be lost at great expense. Finally, there is an inherent security threat posed by the need to transmit potentially sensitive information in a wireless environment. Overall, the handheld PCs would be difficult to use and very expensive to acquire and maintain. The real advantage of the handheld PC posed by both Buisson and Jestin and Doble and Hansman (2003) is that they are relatively small and portable. However, the portability of the physical embodiment of the flight data is not the important aspect of portability. Rather, it is the portability of the information itself, and designers can accomplish such portability in a more elegant manner with larger displays and much simpler, less expensive, and more secure designs.

During the evaluation of DigiStrips, an electronic replacement for paper FPSs developed at Centre D'Études de la Navigation Aérienne (CENA) in France, Mertz and his co-authors presented an array of interface usability research that provides many valuable lessons on the use of touch screens in air traffic control (e.g., Mertz & Lecoanet, 1996; Mertz & Vinot, 1999; Mertz, Chatty, & Vinot, 2000a, 2000b). In the design of DigiStrips, Mertz and his colleagues used different textures to indicate different information on the electronic FPS. For example, a unique texture identified the "grip zone" that controllers could use to move a strip. They used various fonts to differentiate computer entered information and information that was entered by the controller. Mertz and his fellow researchers also determined that animations were very helpful in a number of ways. They used animation to show transitions and state changes, which made the electronic FPS more natural to use. The animations capitalized on the controllers perceptual abilities such as the detection of meaningful movement rather than requiring effortful cognitive activities such as reading, memorizing, and comparing information.

The animations not only lowered the amount of cognitive load, but they also lowered the amount of motor coordination that was required. Using a touch screen interface, controllers could make entries with either hand and multiple users could interact with the flight data whether they were standing or sitting. Mertz and his coauthors also found that the touch screen supported a mutual awareness between controllers because it was easier to see what someone was doing when controllers made inputs using a finger or pen as opposed to a mouse pointer. The touch screens tended to favor simple gestures and required less visual attention due to the direct means of interaction with the flight data. They used simple gesture recognition to perform various actions and to open different menus. For example, vertical gestures were used in the altitude field to activate a menu of higher (upwards gesture) or lower (downwards gesture) values. They implemented horizontal gestures to activate the heading field. Mertz et al. found that these gestures were quick and easy to remember. The touch screen interface also allowed controllers to perform free hand writing easily and naturally. They compared touch screen interaction with mouse and pointer interaction by measuring timing, duration, and rates of recognized gestures.

They found that touch screens were 10% to 14% faster. Users committed a few more errors with the touch screen (90) compared to the mouse (75), but the users were relatively new to using touch screens while they were expert mouse users. Error rates were relatively low overall at 3.9% and 3.2% for touch screens and mouse interactions, respectively. Mertz et al. predicted that the error rates for touch screens would decline as users became more familiar with using the technology. Fourteen of the 90 manipulation errors in the touch screen condition were due to parallax errors. Like the other errors, the authors predict that parallax errors would decline with better, flat screen displays.

Whatever forms any new features of an EFDS take, they must be reliable, provide valid information, and have a wide and demonstrable effect before controllers are likely to accept them. The new features that an EFDS would enable should also provide some incentive for controllers to overcome the well-entrenched FPS and to adopt the new EFDS.

Beyond providing new tools for controllers, researchers and system designers must also gain participation from controllers and controller union representatives during the entire research and development process to aid in overcoming the organizational norms that embody FPSs. Controllers should serve as subject matter experts to help researchers understand the ATCT domain and to provide insight regarding interface design and functionality. By involving controllers throughout the entire process, the FAA can design an interface that best supports the controllers' task rather than simply developing an electronic version of the FPS.

7. Summary and Conclusion

Having the support of controllers is a necessary condition, but not sufficient to ensure the success of an EFDS. Researchers also need to learn more about the true cognitive benefits provided by FPSs. As previously mentioned, there is very little data concerning how controllers in the ATCT perceive and gather flight data, but the ATCT domain poses some familiar questions. The Interaction and Cognitive Resource hypotheses become relevant again and demand the attention of researchers. It is appropriate and necessary to ask these same questions again because the task of controllers in the ATCT is quite different than that of controllers in either the TRACON or ARTCC environment. Our knowledge of how controllers use FPSs in the terminal and en route domains does not allow us to fully understand other domains. During the development of an EFDS for the ATCT, we must know if changes to the presentation of flight data in an EFDS will affect the controllers' ability to find or use that information. We must know if the way that controllers physically interact with the system affects their ability to find and use flight data. Researchers need to employ various part-task or low-fidelity simulations to understand basic cognitive functions, but they must also perform high fidelity, human-in-the-loop simulations to test the concepts they create. The FAA also must develop proper procedures and training to help ensure that controllers use an EFDS effectively. With the support of empirical data and proper system design, the FAA will be able to capitalize on the benefits of an EFDS and mitigate the associated risks.

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Acronyms

ARTCC	Air Route Traffic Control Center
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
ATCT	Airport Traffic Control Tower
ATIS	Air Traffic Information Service
AUS	Austin-Bergstrom International Airport
CD	Clearance Delivery
CENA	Centre D’Études de la Navigation Aérienne
CPDLC	Controller-Pilot Data Link Communications
EFD	Electronic Flight Data
EFDS	Electronic Flight Data System
FAA	Federal Aviation Administration
FD	Flight Data
FDIO	Flight Data Input/Output
FPS	Flight Progress Strip
GC	Ground Control
LC	Local Control
MEM	Memphis International Airport
MKE	Milwaukee Airport
NAS	National Airspace System
NTSB	National Transportation Safety Board
PC	Personal Computer
PHL	Philadelphia International Airport
RA	Resolution Advisory
SFO	San Francisco International Airport
SWIM	System Wide Information Management
TCCC	Tower Control Computer Complex
TEB	Teterboro Airport
TRACON	Terminal Radar Approach Control