FOLLOWING THE PAPER TRAIL: DESIGN CLUES FROM PAPER FLIGHT STRIPS[1]

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We attempted to offer clues based on the current usage of flight progress strips that could be useful in the design of an electronic strip replacement system. An existing database [1] containing information about flight strip marking (frequency, importance, benefits) allowed the identification of seven critical strip markings. We examined the functionality and perceived benefits (i.e., workload, memory, communication, cognitive organization) of these markings and explored how the benefits could manifest in a hypothetical electronic system. Analysis yielded several specific suggestions for designers and three general guidelines.

Introduction

For years, an important tool of the en route controller has been the flight progress strip, a small piece of paper on which is printed all the information included in the filed flight plan of the flight [2]. In the United States, the strip is a 1 7/16" x 6 7/16" rectangle of stiff paper containing 31 fields of information (See Figure 1). Strips provide easy access to information, provide an area that can be annotated by the controller thus serving as an external memory aid, and serve as an artifact that can be moved, offset, and sorted to facilitate organization and communication.

Projected increases in air traffic, together with advances in available technologies, have led many to argue for elimination of the paper flight strip in favor of an electronic flight data object [3, 4]. Others have argued that the flight strip, in its paper form, has become an irreplaceable part of air traffic control [5, 6]. The controversy appears to be a global one [6, 7. Our position on the controversy has been that flight progress strips can be replaced with an electronic substitute [4, 8, 9] if one considers only performance and safety. However, the socio-cultural milieu and the necessity to transition the current workforce to an electronic environment has led us to argue that a transitional system be developed that provides controllers with the functionality provided by the current strips while reducing controllers' dependence on paper [10]. These socio-political and workforce issues are, in our view, critical not only in developing an effective electronic strip replacement but also in insuring that the electronic system will be accepted by the controller workforce.

This position underlies the SPIN (Substituting Paper INformation) program of research undertaken by the Civil Aerospace Medical Institute and Texas Tech University. The current paper represents the third paper in the SPIN project. The first paper [10] presented a rationale for our position based on the literature, on empirical work of our own, and on logical argument. The second paper [1] reported an extensive observation of flight strip use that was intended as a foundation from which an understanding of current strip functionality would emerge. The current paper makes use of that database of strip usage to offer clues to facets of flight data functionality that designers of future systems may want to consider.

There are, in fact, a number of proposed electronic replacements for the paper strip. For example, DigiStrips [11] is an elegant electronic system that essentially reproduces the format of the paper strip with a number of adaptations allowed by digital representation. Currently, Lockheed-Martin is deploying the User Request Evaluation Tool (URET) throughout the US. URET is in use at 6 en route centers and is scheduled to be added to the remaining centers over the next few years. In this paper, we attempt to discuss design implications at an abstract level that can be useful regardless of the particular instantiation of the electronic flight data object.

Purpose

Thus, in an effort to inform the development of a transitional electronic strip replacement that would be accepted by the current workforce, we used the results of an extensive quantitative observational study of paper strips and informal qualitative interviews and observations of URET, to extract information about paper strips and how they might, or have been, implemented electronically. Our intention is not to evaluate existing or proposed

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systems or to offer a specific electronic system, but to give clues to design based on existing functionality and perceived benefits. Although any electronic strip replacement will doubtless evolve in the field, we believe that insuring that the perceived benefits of the most frequent and most important markings are captured is a prudent design decision.

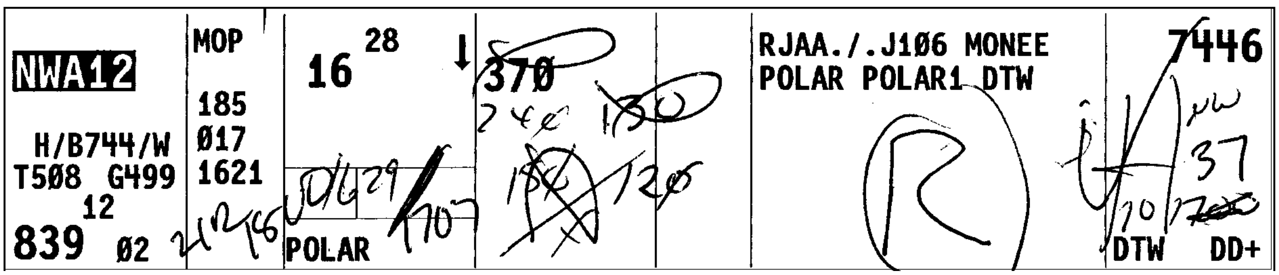

Figure 1. A flight progress strip with illustrative strip marking.

Methods

Quantitative observations: Flight strips

Because the details of our quantitative observations have been reported elsewhere [1], we offer only a summary of those methods here and refer the reader to the original report.

Expert ATC specialist observers recorded the frequency of strip markings and actions at five US en route facilities, Chicago (ZAU), Kansas City (ZKC), Washington (ZDC), Atlanta (ZTL), and Cleveland (ZOB). Observers watched a randomly chosen controller at a randomly chosen sector for 10 minutes. More than 1300 10-min observation periods yielded 34,000 tallies divided among approximately 30 different markings and strip actions.

At the end of an observation period, some controllers were invited for an interview. For our purposes, the critical component of the interview was the perceived benefits of one of the marks they made. Some of these interviews were open ended and some were guided by Likert scales. In the current discussion, we ignore this procedural difference when determining the perceived benefits of each of the critical markings.

Finally, expert controllers from a national panel judged the importance of each of the markings observed.

We used the importance ratings and observations of frequency to identify the most critical strip markings. We then focused on these markings to provide guidance to our search for design implications.

Qualitative observations: URET

Our thinking has also been informed by experiences with the URET system. One of the authors visited each of the six US en route centers at which URET has been deployed: Indianapolis (ZID), Memphis (ZME), Cleveland (ZOB), Chicago (ZAU), Kansas City (ZKC), and Washington (ZDC). URET had been deployed at ZID The visits allowed casual observation of URET use and informal discussions with controllers provided us a perspective of an instantiated electronic strip replacement. This perspective allowed us to shape our interpretations but the visits were not intended to yield data that could be used to offer definitive information about URET.

URET was intended as a D-side tool to aid traffic flow, for example, by facilitating requests for direct routing, and ultimately as a strip replacement. URET has two modes: one, a list mode that presents a single line of flight data for each flight; and two, a conflict-probe mode that presents a graphical depiction of flight paths and the algorithms to detect conflictions 20 minutes into the future. The list mode is more closely related to the current flight strip.

Design implications

In an effort to extract clues about the current system that may aid designers, we studied the earlier data on strip marking benefits. First, in consultation with several subject matter experts, we gained a better understanding of the operational nature of the control activity relevant to the strip marking. We then reviewed the comments made by controllers in the previous interviews [1] to gain an understanding of how the paper strips provided the benefits they were perceived to have. Controllers tended to see workload, memory, communication, and organizational benefits to the paper flight progress strips. Then we attempted to map the markings and the benefits. More specifically, we determined which markings tended to be viewed as having similar benefits. We then speculated on how those benefits could be retained in an electronic system. Finally, we attempted to identify broad-based constraints on the design of electronic flight data that would allow the electronic system to deliver the operational function while providing the human factors benefits identified by the controllers.

Results

Table 1. The 7 most critical markings and their corresponding importance rating and frequency of occurrence. (Adapted from [1]).

Strip Mark	Importance (Geometric)	Frequency (per 10 min)
Altitude clearance coordination	69	.47
Point out	60	.45
Eliminate/ Revise control information	29	.61
Issued Altitude clearance	55	2.90
Issued Route clearance	88	.69
Issued Heading clearance	68	.51
Issued Speed clearance	50	.46

The Critical 7

In the original database [1], the importance ratings and frequency tallies were statistically uncorrelated. The partitioning of the markings based on importance and frequency led to the identification of seven critical markings, high on both importance and frequency. These data for the critical seven marks are reproduced in Table 1. The first two marks listed in the table are related to coordinations and the last five are related to issued clearances. Eliminate/revise control information could be related to either coordination or clearance, depending on what control information is revised. As evident in the table, marks indicating issued altitude clearances were clearly the most frequent and issued route clearances were the most important. Route issued clearance markings also ranked second in frequency among the critical seven marks.

A D-side replacement?

In the US, sectors of en route airspace are controlled either by an individual or by a team of two (occasionally more) controllers. A two-person team comprises a R(adar)-side controller and a D(ata)-side (or RA, radar associate). The R-side monitors the radar and communicates with the pilots. As the name implies, the D-side controller presumably is responsible for the management of the flight data. In fact, we [1] reported earlier that strip marking responsibility actually varies considerably across centers. Markings of coordinations with other sectors or facilities do, in fact, follow the presumption with D-side controllers making most of these markings. However, the responsibility for issued clearance markings varied across centers. In some centers, the R-side makes the majority of these markings, whereas in other centers the D-side is responsible for these markings. Thus, the assumption that any electronic replacement will be "a D-side tool" is simplistic. At Chicago and Atlanta, the R-side, not the D-side, made most of the issued clearance markings.

Expanding on that earlier work, we looked more closely at the Critical-7 markings and more closely at the centers. Division of responsibility between R-side and D-side was clearest at ZAU, where between 95 and 100 percent of the issued clearance markings were made by the *R-side*. ZKC showed almost as clear a division of responsibility, but rather than the R-side, the D-side made most of the issued clearance marks. The variability across centers can be quite striking. For example, whereas the D-side at ZKC made 99% of the issued heading markings, the D-side at ZAU was the one who made such those marks only 4% of the time.

Table 2. Comparison of two centers' strategies across the four critical issued clearances. Entries are percentage of times the D-side made the mark, corrected for amount of traffic.

	Altitude	**Heading**	**Speed**	**Route**
ZKC	86	99	96	85
ZAU	5	4	0	2

Suggestions

- Recognize that issued clearance marks are made by either R-side or D-side, depending on facility

Workload aid

The literature [6, 10] has always implied that one of the primary benefits of the paper system is a reduction of workload, and there are certainly good arguments for paper [12]. In fact, it is likely that for some actions additional keystrokes will be required to achieve the same human-factors benefit that was once obtained simply with the stroke of a pen.

Markings

We were surprised that workload, in fact, was infrequently mentioned as a benefit supplied by strip marking. Only responses to two of the critical seven marks, altitude clearance coordination marks and pointouts, suggested that workload was a significant reason for making the marks, and this was true primarily when the marks were made during team staffing of the sector. For altitude clearance coordination marks, a typical indication would be a circle around the altitude indicating that the altitude clearance has been coordinated with the next sector. For pointouts, both the sector accepting the pointout and the sector giving the pointout might write, for example, P37, indicating that a flight was pointed out to sector 37.

As we will see, these coordination-related marks reduce work primarily by facilitating communication, memory, or both. These marks can help avoid the need to communicate with a teammate. There is an asynchronous component to this benefit: The controller can make the mark at a time convenient for the writer, and the receiving controller can, in turn, process the written information when convenient for the receiver. Without such an indication, controllers must wait until the receiving controller is free to receive an oral indication, or they can do nothing thus potentially resulting in double coordinations, where both controllers coordinate the action.

These marks can also reduce workload by reducing the memory load on the controller. For example, a controller who wishes to pointout a flight to another sector might mark P37 on the flight strip indicating that he has initiated a pointout request and then circle it indicating that the pointout was accepted.

Design implications

In an electronic system, the controller wishing to indicate that altitude was coordinated can indicate the relevant entry by, for example, highlighting a portion of a flight entry, making a checkmark, or typing in some designated text space. The latter is, of course, keystroke intensive, whereas making a checkmark is less so.

Given that there are a number of possible ways for indicating, for example, that an altitude has been coordinated, does not mean that all possible options need to be, or should be, presented. In the US, the desire for individual freedom in choosing strategies often makes it difficult to establish standardization. Without a particular standard procedure in which to indicate altitude coordination, controllers will have a tendency to develop idiosyncratic ones.

A corollary for establishing standard procedures is to have a one-to-one correspondence between functions that designers wish to maintain (e.g., altitude coordination) and the display features available (e.g., checkmark). On occasion, this relationship is instead many-to-one forcing controllers to use the same checkmark for multiple purposes or, again, to develop indiosyncratic uses of the display features.

With pointouts, additional keystrokes would be likely in an electronic system, This is because the casual intuition is that pointouts do not occur with sufficient frequency to warrant a dedicated display feature. In fact, pointout presence in the critical 7 suggest that it may, in fact, warrant such a feature. In a system requiring pointout notes be typed into a general text area, the additional keystrokes may reduce the workload benefit for such marks and controllers may abandon the pointout markings, choosing instead to "remember" information about the pointout. Or, controllers might develop a less keystroke-intensive alternative, like using a slant-0 for the data block (changing the length of the leader line between the data block and target to have a length of 0) to indicate that a flight has been pointed out.

Given that pointouts occur with reasonable frequency (once every 20 minutes in every en route sector), designers might consider a dedicated popup system, in which controllers select the sector number from a limited number of possibilities.

Suggestions

- Recognize that most strip marks were *not* made because they reduced workload.
- Standardize procedures for all electronic replacements with special attention paid to coordination markings like altitude coordination (e.g., checkmark?, where?)
- Minimize keystrokes to indicate a pointout was made.
- Consider a dedicated display feature for pointouts.

Memory aid

The mnemonic value of flight progress strips has been recognized by a number of researchers [4, 5]. Memory aids [13] can be of two types: retrospective and prospective. Retrospective memory aids help remind the operator that some action has already been taken (and, thus, need not be taken again). Prospective memory aids help remind the operator to take some action in the future. Although both types of memory can be aided by flight progress strips, there were virtually no marks made in the original observation study [1] to indicate planning. Thus, we focus our attention here on the markings as a retrospective memory aid.

Some proponents of paper strips have made the argument that the physical actions required to move and write on a strip supply memorial cues that electronic point and click cannot [5]. However, there is no empirical work with controllers suggesting this is true, and in fact some work suggesting that there is no memory impairment when strip marking is eliminated [4] or when strips are transformed to an electronic form [9]

Markings

All seven of the critical marks implicated some memory benefit, but the issued clearance markings especially seem to have a memorial benefit. Issued clearance markings routinely involve writing the new information—altitude, speed, heading, route—near a crossed-out (eliminate/revise control information mark) version of the previous information. Although the marking makes the new information easily accessible, the presence of the new information also serves as a reminder that the controller has already issued the appropriate clearance.

The four issued clearance marks interact with the system in different ways. For altitude clearances, the mark on the strip is redundant with the data block because the new altitude is entered into the system and thus appears on the situation display. For speed and heading clearances, the strip mark is the only record of the clearance (barring contacting the pilot). Finally, for route clearances, like altitude clearances, the information is also in the system, but unlike altitude clearances, the information is not passively present, but instead must be actively retrieved, either through the situation display or the computer readout device (CRD).

The coordination marks also had memorial value, but unlike issued clearances, the coordinated clearance marks are typically physically simple and often nonverbal. For example, coordination of an altitude clearance is typically indicated with a circle around the new altitude **[Not a coordination-related mark]**Nevertheless, these simple marks remind the controller that he or she actually has contacted the neighboring sector or entered the information into the computer.

Design implications

In an electronic system, reminders about actions taken can of course be incorporated, but concerns about display real estate, keystrokes, and clutter can be limiting factors. For the issued clearances, merely having the new flight information displayed is likely to be sufficient given that flight strips serve their mnemonic role in this way. At first blush, electronic keyboard-entry systems seem at a disadvantage to writing on paper, because the latter have an input channel slower than writing on the strips. This disadvantage can be especially pronounced when extend typing is required as, for example, when recording the clearance after issuing a new route. Fortunately, For altitude issued and route issued, the system can take advantage of the fact that the new information exists in the computer, and thus the system can simply display that information for altitude-issued and route-issued clearances, this information is entered into the current, strip-based system by keystroke as well. In fact, entering route information in the current system is rather difficult, and it is likely that a new system will allow easier entry. Thus, if the new system either makes entry simpler than the current system, or is structured to allow positive transfer from existing input procedures, altitude-issued and route-issued clearances could circumvent the keystroke problem.

There are two caveats to this optimistic conclusion for route information. One caveat is that the complete information from a long route may not necessarily be apparent in an electronic system with limited display real estate, requiring scrolling within the route window (this is true, by the way, with the current CRD as well). A second caveat comes from the presumption that the new electronic system would be a D-side tool. If, in fact, entering information differs depending whether you are using the primary system or the electronic flight data system you may see either difficulties when switching between R-side and D-side positions, or you may find controllers in an individual staffing situation moving between keyboards simply to take advantage of the easier entry system.

Although route and altitude marks can circumvent the keystroke problem, for speed and heading clearances, because these clearances are not entered into the computer, cannot. Because the number of additional keystrokes is small, a designer might choose simply to let the controller enter the information numerically. If, instead, minimizing keystrokes was viewed as critical, popup windows that allowed selection of speeds or headings from a list could be successful. Again, controllers may choose simply to remember the speed and heading clearances rather than enter the information.

Although coordination-related marks do not have the mnemonic value that issued clearances have, controllers did indicate that the marks did function as an external memory aid. We suspect that some coordination marks, in some situations, do have powerful mnemonic consequences. Consider that some coordination marks are made simply to indicate that intended changes have actually been entered into the computer. Other coordination-related marks are made to indicate that flight changes have been passed to the next sector or facility. These second types of coordination marks are likely to be valuable to memory. Although merely seeing the current flight information may be sufficient to indicate coordination with the system computer, such a display is insufficient to signal that the information has been coordinated with another sector or facility. To remind the controller that he has communicated the information, an electronic environment could, as we suggested above, use checkmarks or highlighting. However, one aspect of coordination marking in the paper system that is unlikely to be captured in an electronic one is history, that is the fact that previous, now invalid, flight information nevertheless remains visible, even if crossed through. Maintaining history in an electronic environment places severe demands on display real estate. In addition, we are unaware of any evidence that displaying history information actually improves memory or performance. Thus, we do not argue that some representation of history should be maintained in the new system.

Suggestions

- For altitude and route clearances, take advantage of the fact the information is in the system by displaying information entered into the primary system.
- Make relevant route information available without scrolling, perhaps by presenting information elliptically around a sector fix and destination or use a second line.
- Automatically highlight information changed through the computer (e.g., altitude, route). The highlighting can disappear after a short period of time (or the controller could click on it to make it disappear).
- Make all information easily entered from either position
- When standardizing coordination markings, give special consideration to coordination marks indicating contact with another sector or facility.

Communication aid

Marks on flight progress strips can also serve to alert the other member of a sector team that a control action has been taken. The R-side and D-side controller can, and typically do, communicate in a variety of ways—oral, written, and nonverbal. Sometimes this communication is synchronous; that is the receiving controller hears or reads what the sending controller has communicating at the time it is being communicating. Other times, this communication is asynchronous; that is, like e-mail, the sending controller communicates, but the receiving controller does not process the information until later, presumably when he or she is less busy or when he or she needs the information. Strip marking is a particularly important vehicle in asynchronous communication.

Markings

Unlike memory, which was aided primarily by the issued clearance markings and somewhat by the coordination-related markings, communication seems to be aided primarily by the coordination-related markings and only somewhat by the issued clearance markings. More specifically, communication was aided by all the coordination-related markings:

pointouts, and altitude clearance coordinations . It was also aided by markings indicating route-issued clearances and to a lesser extent by markings indicating heading-issued clearances.

The communication value of the coordination markings is apparent. When one member of a controller team secures a pointout or coordinates an altitude clearance, the marking alerts the controller's teammate that the information has been passed to another controller. These marks have this value because both members of the team can see the strip bay and the markings. This simple point is important because if designers do not realize that strip markings have communication benefits, then the potential for a design that does not place the electronic aid between the controller teammates or does not allow both team members to update information will present problems.

Marks indicating that route and heading clearances were issued were also indicated to have communication value. We believe that the reason these clearances, and not others, were perceived to have communicative value is that the information for these clearances is not passively available on the situation display. For example, unlike an altitude clearance which appears as a change in the datablock on the situation display a route change does not appear on the situation display unless a route readout or route display is requested. Thus, the strip marking plays the role of a passive communication device for routing.

Design implications

In an electronic system, it is important that the receiving controller be able to locate and read the information from the sending controller. A number of general human-factors considerations about displays should be considered: size of font, contrast, and so on. In addition, some electronic systems attempt to take advantage of the underlying computational possibilities by having the computer, rather than the operator, sort incoming information, in our case, flight data entries. However, for entries that serve a communication function, automatic sorting could make it difficult to locate relevant information as flight entries change location. In a related vein, to locate the information most efficiently, the sorting preference of the electronic system controller should be compatible with the preferences of the teammate.

Because the coordination markings are especially important for communication, the standardization of these marks should keep in mind that the information must be processed by the more distant controller of the pair. Constraints placed on these decisions by real estate and clutter can be partially addressed by the fact that route clearances, but not altitude clearances, play a role in communication.

Suggestions

- The electronic flight data display should be visible from both (all) controller positions.
- Both controllers should be able to enter and modify information on the display.
- Flight information that relies on the electronic system for communication (e.g., route) should be given special status over flight information that does not (e.g., altitude).
- The system should not usurp positioning of the flight data entries (i.e., no automatic sorting)
- Standardization of all marking replacements should take into account that options given one controller (e.g., sorting preference) could affect the other.

Cognitive organization aid

The final benefit controllers saw in their flight strip markings was as an aid in organizing the flight situation. The marks did not seem to be a means to organize the strips themselves. Rather, the open-ended comments suggested the marking served as a means of organizing the situation (e.g., ". . . a/c is doing something unusual."; "to indicate where a/c will cross fix and at what assigned altitude.").

Markings

The only critical marks that suggested a large organizational role were altitude clearance coordinations and route-issued clearance. We suspect that these marks, and not others, were seen as having organizational benefits because they allowed controllers to cluster flights along dimensions not apparent on the two-dimensional plan view display.

Altitude information is not represented graphically on the plan view display and thus using coordinated altitude information can aid controllers in organizing flights along the z-axis (and time). Similarly, the fixes over which aircraft will fly and the final destinations of those aircraft is not apparent on the plan view display. Thus, using route information can aid controllers in clustering together those flights heading over the same fix or those going to the same destination.

Design implications

In an electronic system, the organizational value achieved by marking altitude clearance coordinations and issued route clearances should be achievable in any system that allows those marks to be made. In addition, it may be possible to emphasize this organization by allowing controllers to cluster the list entries either by physically moving them or by otherwise emphasizing the common altitude, fix, or time of flights in the sector. In fact, some efforts to design an electronic aid do exactly that [14].

Suggestions

- Controllers should be allowed to make multiple clusters, rather than sort, list entries on altitude and route information.

Conclusions

We considered the seven critical flight strip markings extracted from a database of frequency, importance, and benefits of flight strip markings [1]. Detailed consideration of these markings allowed us to determine the functional value and benefits of those strip markings and how they might be transferred to an electronic system. We offered detailed suggestions about particular markings.

From these suggestions, we can also extract three overarching guidelines. The new electronic system should:

- Give controllers maximum flexibility and control in placement of the electronic flight data entries.
- Standardize how controllers indicate information, especially coordination information
- Have both the display of flight data and the ability to change that information accessible to both members of a controller team.

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Key Words

Flight progress strips, automation, flight data object, cognitive benefits, URET, strip replacement, HCI, interface design

Biographies

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