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POSITION PAPER

# Spinning paper into glass: transforming flight progress strips

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## Overview

The purpose of this paper is to describe how flight progress strips are currently used in United States (US) en route air traffic control (ATC) and to discuss the Federal Aviation Administration's (FAA's) objective of eliminating them. The paper will begin by briefly describing the US ATC system, in particular the en route environment, then will describe how flight strips are used. Issues surrounding the replacement of flight strips will be discussed, along with the role of various methods of inquiry in answering questions about appropriate strip replacements. We provide several reasons for taking the position that flight progress strips can be eliminated, but argue that for a variety of reasons a transitional system will be valuable for moving the current, strip-dependent workforce away from paper.

## US en route Air Traffic Control

To accomplish its primary purpose 'to prevent a collision between aircraft operating in the system and to organise and expedite the flow of traffic' (Federal Aviation Administration, 2001; Section 2-1-1), the ATC system employs four

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types of facilities to provide ATC services. These are flight service stations (FSS), ATC towers, terminal radar approach control (TRACON) facilities, and air route traffic control centres (ARTCCs, also called 'en route facilities' or 'centres'). Employees of each type of facility provide a different type of ATC service. En route controllers, the focus of this article, work in centres using radar or non-radar procedures to authorise the movement of aircraft operating between terminal areas. A centre may also provide limited approach control services for aircraft landing at airports that do not provide these services.

The men and women in the towers, terminals, and centres around the US excel at accomplishing their primary goal of safety. Although the events of September 11th have increased the concern of the flying public, taking a commercial flight in the industrialised world remains one of the safest forms of transportation. If we focus on the mishaps caused by the air traffic control system, the safety performance is remarkable. For example, since 1983, the National Traffic Safety Board (NTSB) identified en route ATC as a contributory factor in only two accidents, one landing and one terrain (en route ATC was never a primary factor). If we hold ATC to an even higher standard of 'near misses' that is, operational errors, the level of safety achieved remains superlative. In the US en route environment, an operational error occurs when aircraft violate separation standards; for example, in high altitude en route environments (29,000 feet or above), the standard is 5 nm lateral separation or 2000 ft vertical separation. The percentage of flight legs that result in an operational error is well less than 1% (see, for example, Durso, Truitt, Hackworth, Crutchfield and Manning, 1997; Rodgers and Nye, 1993).

The airspace assigned to a centre is divided into smaller segments called areas of specialisation, which are further divided into even smaller, interrelated airspace segments called sectors. Sectors are classified as Radar, Non-Radar, or Oceanic and are sub-classified by their altitude strata (high, low, super-high, or super-low). Fully certified en route controllers, called Certified Professional Controllers (CPCs), control traffic at all sectors grouped within one area of specialisation and do not control traffic at sectors in any other areas.

One, two, or more controllers can staff a sector depending on the overall level of activity. The ATC tasks to be completed remain the same regardless of the staffing. When one controller is present, he or she must perform all the duties associated with controlling traffic at that sector. However, when more than one controller is present, there is not a universal approach to how the responsibilities are divided (Federal Aviation Administration, 2001; Section 2-10-1). In general, the Radar (R) controller ensures separation, issues control instructions to pilots, operates the radios, accepts and initiates transfer of radar identification for an aircraft from one controller to another (i.e., makes and takes handoffs), coordinates with the Radar Associate (RA) controller, scans the radar display, ensures that clearances issued or received are recorded properly, and ensures the R-side equipment can be used by all members of the sector team. The Radar

Associate (RA) controller, also referred to as 'D-Side' or 'Manual Controller,' assists the R controller. The RA controller helps ensure separation, initiates control instructions, communicates with controllers at the same or other facilities, accepts and initiates automated or non-automated handoffs, ensures that the R controller is made aware of any action taken, conducts coordination, monitors radio communications, scans flight progress data, manages data recorded on flight progress strips, ensures that clearances issued or received are accurately recorded, and ensures the RA equipment can be used by all members of the sector team. However, there is considerable variability across centres with respect to the division of responsibilities for the R and RA controllers. Teams staffing a sector can be, on occasion, larger than two. For example, 'trackers' assist at a busy sector, offloading some of the radar controller's duties.

*Equipment and information used in en route ATC*

En route radar controllers use secondary surveillance radar to identify aircraft operating under instrument flight rules (IFR). The radar system interrogates a transponder on an aircraft, which generates a reply. Computer processing of the information provided by the transponder allows display of information about the altitude and location of the aircraft. The radar information is correlated with flight data processed in parallel, which allows the computer to match the aircraft's identity with its position.

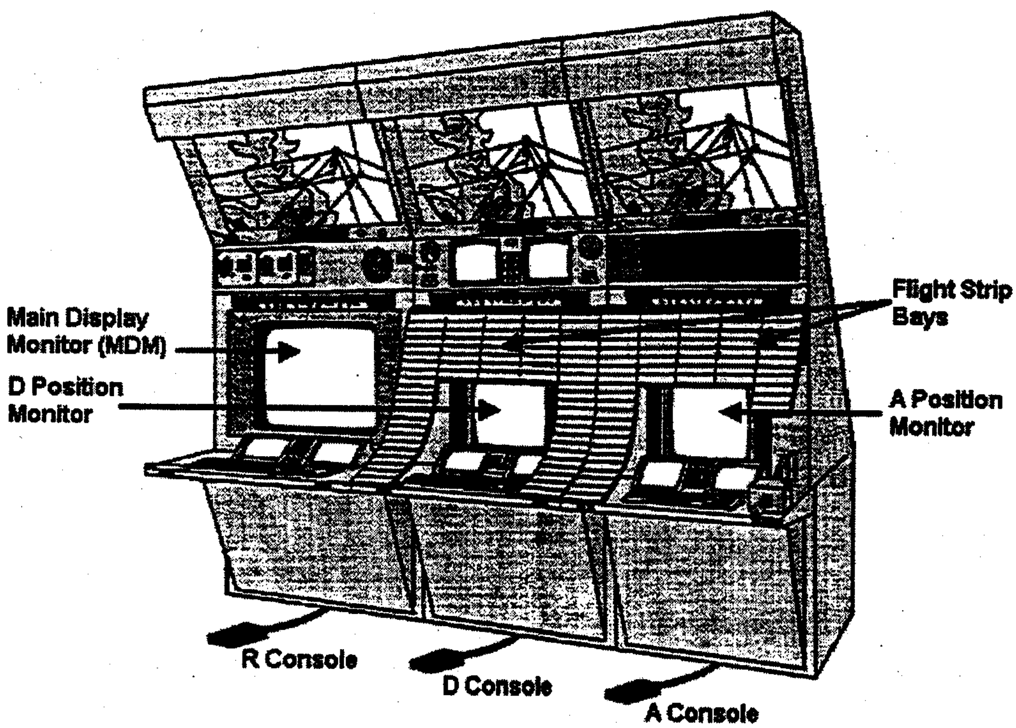


**Figure 1 Drawing of the display system replacement (DSR)**

In the display system replacement (DSR) work environment (see figure 1) radar controllers view the combination of aircraft position and identity information on a situation display (SD, also called a plan view logical display), a window generated on a 20' x 20' main display monitor (MDM). Each radar-tracked aircraft on the display is accompanied by a 'data block.' A data block consists of a position symbol (indicating the type of tracking employed), and up to (as of this writing) three lines of alphanumeric data concerning the flight, a line connecting the position symbol with the alphanumeric data, and a line predicting the aircraft's future position, based on flight plan data.

Controllers use a keyboard, keypad, and a trackball to enter and retrieve information about an aircraft's flight plan. Messages are displayed on several 'views' (windows) located on the R controller's or on auxiliary displays located at the RA controller's workstation. Controllers use a variety of communication devices, including telephone landlines and radio frequencies that allow them to contact pilots, other facilities, and other sector workstations within the ARTCC.

En route controllers also use small pieces of paper called flight progress strips (FPSs, also known as 'flight strips' or just 'strips') on which are printed all the information about a flight that is included in the filed flight plan. The en route flight strip is a $1\,^{7}/_{16}$' x $6\,^{7}/_{16}$' (36.6mm x 164.6mm) piece of stiff paper containing 31 blocks or fields that can contain flight plan information (see figure 2).

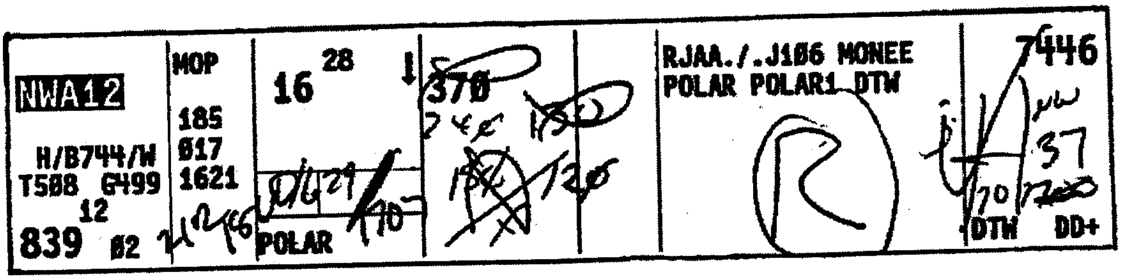


**Figure 2 Example of a flight progress strip currently used in ARTCC facilities. It shows both printed information and the controller's handwritten markings**

Before radar was available, controllers used flight strips to sequence and separate all aircraft. Strips are still used to separate aircraft in environments where radar is not available. When only primary radar (which showed only aircraft positions, but did not include associated flight plan data) was used, controllers studied strips extensively to maintain situation awareness about the identities and characteristics of aircraft moving through the sector and identify potential conflicts. Even when secondary radar was developed, flight strips retained their utility because they provided controllers with access to flight plan data that are not displayed in the data block (such as aircraft type, which indicates the aircraft's performance characteristics). Controllers developed additional uses for strips by moving or offsetting them to indicate that an aircraft was particularly noteworthy, or writing information on them about control actions that are not updated in the flight plan or plans for future activities. Finally, strips are the only backup in case of system failure—if the power goes off, a controller can look at these pieces of paper to identify aircraft that are flying through the sector.

### *General flight strip uses*

Flight strips are used in three different ways. First, strips can be used as an easy reference to a complete set of information about an aircraft's flight plan. Although a considerable amount of important flight plan information is included in the data block (e.g. aircraft ID, assigned and reported altitudes, computer ID, ground speed, handoff indicator, not all flight plan information is displayed there (notably the aircraft type and route/destination). A controller needs to know the aircraft type for each aircraft under control in order to determine its performance characteristics. Such information is useful if, for example, the controller needs to decide which aircraft should go first in a sequence. Because the aircraft type is not shown in the data block, the controller must instead refer to some auxiliary source of information. The controller can make a computer entry that will display an aircraft's flight plan on the computer readout device (CRD) view or can glance at the flight strips. Controllers also need to know the route of flight and destination for each aircraft. If an aircraft will land in the controlling sector or an adjacent sector, the controller needs to know the destination in order to plan its descent. If an aircraft needs to divert around weather, knowledge about its route and destination could influence whether the controller clears the pilot to deviate to the left or right. Some facilities use an automation patch that displays an aircraft's destination in the data block, but no single destination patch is universally employed and some facilities do not use a destination patch at all. Controllers who cannot see the destination in the data block or need more information about an aircraft's route of flight can either refer to the strips or make a computer entry to bring up the flight plan on the CRD view (although if the route is too long, not all of it will be displayed).

A second use for flight strips involves annotating activity concerning an aircraft's flight plan that has either already been completed or needs to be completed in the future. To do this, controllers can either write information on strips or take some action using them. Writing on strips can provide a record of activities that occurred within the sector regarding a particular flight (e.g. issued clearance), can indicate that a controller has coordinated with another controller about a clearance (e.g. coordinated clearance), or can be a reminder that some action needs to be taken in the future (e.g. planned clearance). Some of the information written on strips can also be entered into the computer to update the flight plan (e.g. an altitude clearance) but other information cannot (e.g. heading, speed, holding instructions). Clearances that are issued, planned, or coordinated can be recorded on strips using distinctive annotations, such as writing planned clearances in red or circling information to indicate that coordination has occurred. Other kinds of information not specifically related to clearances, such as pointouts, or releasing/receiving control of an aircraft to another controller are also recorded, as are unusual events, such as issuing infrequently used radio frequencies, comments, pilot information, and so on.

A third use for flight strips is to organise or highlight information. Strips may be re-sorted or moved when an event occurs, such as when an aircraft takes off from an airport or enters from another sector. Strips may also be offset to indicate, for example, that the R controller needs to take an action (or pay special attention to an aircraft) or to communicate to the RA controller that something needs to be done. In addition, the R controller may point to information written on the strip for the benefit of the RA controller when he/she is busy talking with another pilot.

### *Current use of flight strips*

If strips are used as prescribed by regulations, interacting with strips and managing them are important parts of the controller's job. We (Vortac, Edwards, Jones, Manning and Rotter, 1993; Vortac, Edwards and Manning, 1994) observed ATC instructors while they controlled simulated air traffic either individually or as an R/RA sector team. We used Pathfinder network analysis to produce a graph of the activities normally used in ATC. Figure 3 shows an illustrative network from that analysis, specifically from individual controllers working the high-complexity scenarios. In this graph, and in all the other graphs of high or low complexity, individual or team staffing, writing on the strips (WRITE) was a central (in a graph-theoretic sense) component of the networks. In addition, the connection between writing on the strips and manipulating them (WRITE → MANIP) occurred frequently and appeared in all the graphs.

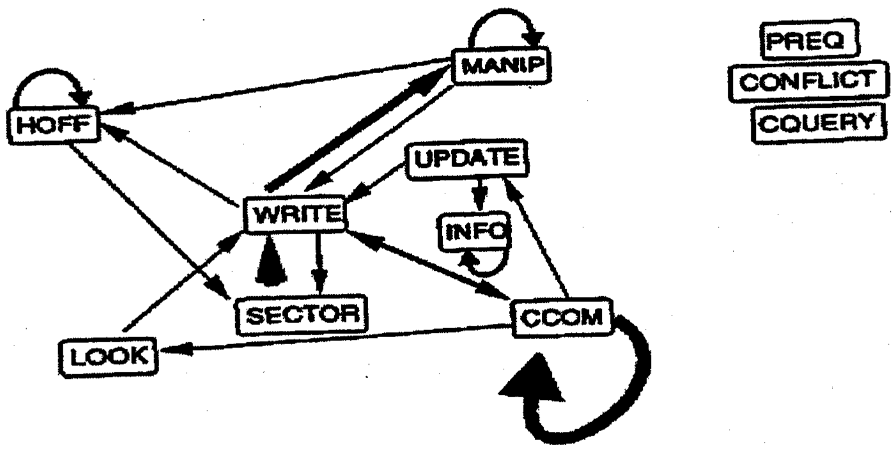


**Figure 3 Pathfinder graphs showing interconnections among some major ATC functions. From Vortac, Edwards and Manning (1994). CCOM = Controller command; PREQ = Pilot Request; CQUERY = Controller query**

The graphs also suggested that there was a 'board management' module, bursts of activity during which the controller would manage the strips. The triggers for writing on a strip were quite predictable (Edwards, Fuller, Vortac and Manning, 1995). Writing at time, *t*, depended on whether an aircraft entered the sector, whether the controller issued a command, and, consistent with the idea of bursts of board management, whether the controller had just written on a strip. Overall, these data indicated that board management was a frequent and central part of the controller's behaviours, but one that occurred as bursts of distinct activity, what Vortac (1993) referred to as a behavioural module. However, these data alone only indicate that changing interactions with the strips will have a large impact on the controller, not whether the change would be negative or positive. Although behavioural modules are possible targets for successful automation (Vortac, 1993), their existence does not suggest that they should be automated. These data also do not indicate the reason for strip activity. Because strip activities are typically mandated and because current day controllers have been interacting with strips in this way for years, board management may be central to ATC.

MacKay (1999) described how a team of controllers at the Athis Mons centre near Paris used paper flight strips. Controllers annotated strips to note an agreement between the controller and pilot regarding changes to an aircraft's assigned route or flight level. Controller scanning patterns started with an overall view of the traffic using the radar display and then focused on detailed information about specific aircraft using the strips. MacKay proposed that flight strips allow controllers to offload mental effort because they record important information on the strips and sort or offset them to better organise or highlight information. While indicating that annotations are important, MacKay (1999) observed that 'a few senior controllers write very little, usually annotating strips quickly just before a new team arrives.' Another important function of the flight strip is to promote communications between members of the controller team. Movement of a strip into a controller's peripheral or focal vision is one method to communicate the urgency with which some action needs to be taken with a specific flight.

Although MacKay (1999) provided an interesting perspective on the use of strips in several types of air traffic facilities, she did not provide any information about the relative frequency with which individual controllers used particular strategies for dealing with strips. Until recently, no frequency data were available to describe how US en route controllers used strips when controlling live traffic. However, in 2001, Durso, Batsakes, Crutchfield, Braden and Manning (under review) conducted an extensive observational study that examined operational flight strip usage at five en route facilities (Kansas City, Chicago, Atlanta, Cleveland and Washington centres) scheduled to receive a decision aid that is intended to replace most paper flight strips. The purpose of the study was to determine how flight strips are actually used so that operational needs might be otherwise accommodated if paper flight strips were eliminated.

In the first part of the study, trained CPCs observed flight strip usage by R controllers, RA controllers, and other controllers at different types of sectors pre-selected randomly. The observers recorded each time a controller made a strip marking or action during 10-minute observation periods. Approximately 34,000 strip markings and actions were recorded using this methodology. About 2.6 marks, on the average, were made during every minute.

The frequency data derived from the observational study were then matched with a set of importance ratings provided by a group of controllers involved in the development of the en route decision aid for each strip marking and action. For the most part, marks and actions categorised as high frequency and high importance reflected issued clearances. Marks and actions categorised as high importance but low frequency consisted of coordinated clearances. Marks and actions categorised as low in both frequency and importance consisted of planned clearances. Finally, several other markings and actions, including those that constituted four of the five most frequent observations at every facility, fell in the high frequency but low importance category (e.g. incoming and outgoing radar and communications).

The results suggest that strip marking occurs frequently in the en route environment. Observing strip marking for eight hours at one sector alone would witness 1,250 interactions with the strips. Controllers often perform certain actions using the strips and make certain marks frequently. However, frequent marks were not always important and important marks were not always frequent. Thus, frequency of usage should not be the only thing considered when trying to prioritise automation of flight strip functions.

In the second part of the study, controllers were interviewed to determine why they made certain strip markings and actions. About 84% of the controllers interviewed felt that the marks they discussed were beneficial for what were categorised as memory, communication, organisation, and workload reduction. Perceived value depended on the strip activity. For example, marks related to issued clearances were thought to have primarily communication but also some memorial value. Recording planned clearances also has benefits, but only for controllers working alone and not as part of a team. Non-marking actions involving strips primarily benefit members of the controller team and are seen as helping to organise flight information.

Thus, controllers see the strips and their interactions with them as beneficial in particular ways. Some are thought to aid memory, some workload, some organisation, and many aid communication. Perhaps most critical, those marks that were both frequent and important are seen as communication and memory aids.

### *Automation of flight progress data*

The FAA's planning documents describe an ATC system that is based on an expanded version of electronic flight data that will eventually eliminate the use of paper flight strips (Federal Aviation Administration, 1999). According to the FAA's NAS Architecture V4.0 (1999) new applications software will have the following capabilities:

- new and improved controller decision support tools
- utilisation of advanced surveillance and communication information methods
- integration with NAS-wide information service to facilitate data sharing.

Tools to be introduced in the first phase of en route automation (called Free Flight Phase 1) include a decision aid that predicts conflicts up to 20 minutes in advance, called the user request evaluation tool (URET) core capabilities limited deployment (CCLD). The traffic management advisor – single center (TMA SC) is another Free Flight Phase 1 tool that can be used by en route controllers for arrival sequencing. These tools are envisioned to provide a variety of benefits, such as user flexibility in selecting flight paths, efficient use of airspace, improved traffic flow, and increased safety through improved conflict prediction and avoidance capabilities.

Modern programming procedures take seriously the notion of data structure, and thus future enhancements to en route automation will depend on the implementation of a data structure called the 'flight object' (Federal Aviation Administration, 1999). The flight object will contain all the information about a flight, starting with the filed flight plan, but will update automatically as the flight progresses. The flight object will then be retained as the record of each flight as it actually occurred. The use of the flight object will allow more accurate flight data to be shared across ATC facilities and with other NAS users.

*Is technological change inevitable?*

It is easy to believe that once a more modern technology exists, its use is inevitable, and discussions such as the one represented here are not relevant or are merely an academic exercise. There certainly are hints of inevitability in some discussions of the automation of flight progress strips. The silicon snowball rolling down the hills in business and industry has indeed been a formidable force, although as Landauer (1995) pointed out, not necessarily a productive one. Genetically engineered and irradiated foods, despite opposition, are other examples. It is, in fact, often the case that we will use a technology merely because we can; the operators adapt to the instrumentality, rather than the reverse. Human factors professionals understand the difficulty of trying to have an impact on products scheduled to be shipped tomorrow. However, historically, the technological tide has been stemmed on occasion. Recently, nuclear power was seriously curtailed by public opinion associated with accidents at Chernobyl and Three Mile Island. Major disasters are not, however, the only way to slow technology.

Historical incidents of new technology being resisted, sometimes successfully, have parallels in the ATC debate over flight progress strips. In the early 19th century, violent uprisings were held in England to protest the introduction of steam-powered weaving equipment, which was used to produce cloth that replaced hand-woven goods (Englander and Downing, 1988). The craftsmen, who had held a monopoly on their products, were replaced by equipment that could be operated by unskilled labourers to produce (what were considered by the craftsmen to be 'inferior') goods in a significantly shorter period. Thus, the skilled craftsmen, formerly independent contractors, were forced to become factory workers who earned much lower wages than they did previously. Some of the craftsmen rebelled, destroying the new equipment and burning the factor owners' homes. These 'Luddites,' named after Ned Ludd, a craftsman who was blamed for breaking some factory equipment, were arrested and many were convicted and either imprisoned or executed by the British government. Thus, although common use of the term Luddite connotes an unreasonable fear of technology, the historical facts suggest that a more complex debate about responsibility, quality, and livelihood existed.

Noel Perrin (1979) details in *Giving Up the Gun* how the Japanese adopted and then abandoned the gun, while Europeans rapidly replaced the sword. The reasons that the Japanese (but not the Europeans) reverted to the sword may have lessons relevant to the current flight strip debate. Added to the sword's (the strip's) ability to do the job of protecting islands (separating aircraft) there was a lack of universal support by the Samurai (controller) workforce and a general reaction against change initiated from the foreign, West (FAA). Most interesting is Perrin's argument that the new weapon did not fit in any aesthetic sense: the motions associated with a sword fit with the Japanese's sense of motion, but using a gun violated that sense. This is a similar analogy to the position held by some controllers and researchers: The strip fits seamlessly into the ATC environment—the computerised alternative may not.

## To spin or not to spin? The flight strip conundrum

There is an inconsistency in the FAA's philosophy about the use of paper flight progress strips. On the one hand, there is a belief that flight progress data must be automated in order to increase NAS efficiency. On the other hand, there is another belief that retention of paper flight progress strips is necessary to ensure NAS safety. The FAA's recognition of both sides of the issue reflects the debate taking place throughout the US and in global ATC communities.

The focus of some research and more speculation has been on the consequences of removing the paper flight strip from the controller's arsenal. The issue has proven to be quite controversial for a number of reasons. The discussion has been on occasion contentious. Some view the issue as union versus management, as controller versus FAA. Some see it as an argument of those wanting to add technology simply because we can, against those concerned with safety; or as those stuck in the technological past against visionaries looking toward the future.

Because air traffic control is a high-risk, safety-critical industrial task, and because in its current state the level of safety is incredibly high, some stakeholders are naturally reluctant to 'fix something that isn't broken.' The controller, with the added issues of being the individual who must pay the legal—and psychological—debt should a catastrophe occur, is often an especially adamant proponent of the status quo.

The argument is sometimes made that using paper flight strips, especially in today's environment, is necessary to ensure the safety of the NAS. Presently, strips provide the only way to separate aircraft in US non-radar and oceanic environments. Even today, some sectors have no radar coverage while others have only partial radar coverage. No one disagrees that currently strips must be used to control traffic in non-radar environments. However, in the future, the use of global positioning system (GPS) satellites and automatic dependent surveillance – broadcast (ADS-B) may allow using a graphic display of non-radar information that supports more effective conduct of ATC, perhaps even involving a reduction in separation standards. Nevertheless, for the purposes of the current paper we restrict our arguments to the most immediate concern—can strips be eliminated in radar environments?

## How do we decide?

The question of what information should enter the decision process is obviously an important one. Depending on to whom one listens, strips can be an indispensable resource or an historical leftover. Thus, our consideration of different sources of information is more than an academic exercise because the ultimate fate of the paper flight progress strip varies depending on the sources of information given the most weight.

### *Ask the engineer?*

How should we decide whether or not to replace paper flight progress strips? One possibility is to allow the software engineer, who, after all, will be responsible for the coding of the final interface. However, the perspective of the engineer makes it difficult to discriminate possible use from valuable use. In addition, it is well understood by software engineers with a concern for their clients that this perspective requires testing with human users. In fact, the field of human-computer interaction exists because of the engineer's inability to understand the user.

*Ask the controller?*

One might think, and several have argued, that a good start is to consider the opinion of the expert user, in this case the ATC specialist. Who better, one might argue, to decide whether strips are needed? Although certainly a place to start, such surveys should not be a solution for a number of reasons. First, it is often difficult to reflect on devices used every day; a concern that would apply to the routine use of the strip by today's controllers. Just as engineers are thought to have trouble discriminating possible use from valuable use, controllers understandably seem to have difficulty discriminating required use from valuable use (e.g. Durso et al., under review). Second, people, like outside observers, have only inferential, not privileged, access to their thought processes; controllers would not necessarily be able to tell why they made a particular decision (e.g. Nisbett and Wilson, 1977). A compelling illustration comes from K. Patricia Cross (1992) who suggested that if we asked users of iceboxes in the early part of the last century to indicate what they needed or the improvements they would like, the answer would have been more ice, more often—not chemical refrigeration. In Durso et al. (under review), responses to interview questions seeking alternatives to particular strip markings was uninformative. For example, between 15% and 50% of the controllers, when asked what they could do rather than make their strip mark, believed there was no feasible alternative to making the specific mark or suggested making another strip mark. Third, users do not always agree on the value of a device. For strips, despite hyperbole in the literature to the contrary that 'controllers like strips,' (MacKay, 1999), we have found no unanimity of opinion, at least not in the United States. We have spoken with controllers who passionately cling to their strips, as well as those who blithely dismiss their value altogether. In fact, in Albright, Truitt, Barile, Vortac and Manning (1995), only one of 20 field controllers thought the strip could not be eliminated. Finally, controllers are no more likely to understand the scientific principles of control, generalisation, and causality than would any other person without training in scientific methods.

Nevertheless, input from expert users is a good start; an essential first step. This is true, not only because they understand their jobs better than anyone else, but also because some form of controller participation is needed to secure acceptance of the new system (Wickens, Mavor, Parasuraman and McGee, 1988). The FAA has, in fact, sponsored a number of workgroups on which controllers, supervisors, and researchers participate to identify specifications for new technologies. Unfortunately, turnover is sometimes rapid and because different controllers have different opinions, the development of specifications is sometimes slowed by changes.

Might the notion that controllers should decide be carried further, beyond workgroups and advisory panels? Perhaps controllers in the field could decide, on a strip-by-strip basis, whether or not to post a particular strip and whether or not to mark one that is posted. Truitt, Durso, Crutchfield, Moertl and Manning (2000) tested just such a procedure. Field controllers from Cleveland and Jacksonville ARTCCs controlled high-fidelity simulations either as they normally did or using an optional posting/marking procedure. Controllers posted and marked fewer strips in the optional condition as would be expected. Nevertheless, there were no detrimental effects in performance, workload, or team communication; and controllers preferred the optional posting procedure. Unfortunately, such optional procedures are inherently problematic because a controller who prefers using strips may relieve one who does not use strips at all. Preparing the sector for relief in such a situation would be, under the optional posting system, problematic. This is illustrative of a more general problem: without regulations, communication breaks down.

*Ask the anthropologist?*

One problem with relying entirely on controllers is that they are not researchers. Perhaps one solution would be to have researchers become intimately familiar with the ATC situation. This is what anthropological approaches attempt to do.

To put our comments in context, we agree that the anthropological view has merit, especially in the willingness of researchers to learn the intimate details of the system—the environment, tasks, and operators—they are investigating. Consideration at this depth can certainly help frame research questions appropriately and prevent wasted time and effort.

Several researchers have taken an ethnographic perspective in an attempt to understand air traffic control (e.g. Berndtsson and Normark, 1999; Hughes, Randall and Shapiro, 1992; MacKay, 1999). Work by MacKay and by Berndtsson and Normark are perhaps some of the best and most recent investigations of air traffic control that take an anthropological approach. The two studies differ in interesting ways, including their apparent goals. Berndtsson and Normark do a solid job of describing what it is like to be a Copenhagen controller. The report has tremendous value to anyone interested in conducting research in that domain and to researchers conducting ATC research in general. The work is almost exclusively descriptive, and shows uncharacteristic restraint in keeping conclusions from going beyond those which the anthropological methods and data allow.

MacKay (1999) also used ethnographic procedures and focused more exclusively on flight progress strips than did Berndtsson and Normark. The MacKay (1999) report also does a good job of description, but her attempts to go beyond this level of analysis are often problematic. Statements such as 'Air traffic controllers like paper flight strips' (p. 315), 'controllers subconsciously prepare for the arrival of new aircraft when they hear the sound of the strip printer,' (p. 326), 'paper strips…take advantage of tactile memory' (p. 322) are non sequiturs and although some of the statements may be true, the casual use of words like *subconsciously* make it difficult to treat such statements as testable hypotheses.

Such anthropological investigations, partly because little quantitative information is provided, make it difficult to separate the data from the researcher's interpretation. So when MacKay (1999) states that '(Maastricht) controllers were surprised at the complexity of the situation in Paris' (p. 334) and then in the same sentence adds that 'we had the sense that those (Maastricht) controllers were working harder' is a good example of how it is difficult to determine where data end and interpretation begins.

Certainly a researcher who enters an unfamiliar environment will bring a different perspective than the operators, in our case the controllers, who work in it. The anthropologist can, for example, help discriminate valuable use from either required use or possible use. By making explicit the implicit, this different, but informed, perspective can lead to insights and solutions not considered by those who have developed a functional fixedness or cognitive set about their workplace. Of course, if the anthropologist becomes too much like a controller in thinking, then he or she may come to believe that the only way to improve the system is to get 'more ice.'

As the anthropologists becomes more familiar with the environment, they become more like the controllers in their understanding of the situation. Why prefer their opinion rather than the controller's? Ideally, the anthropologist will be an objective observer who has developed some of the knowledge of the operator without being biased by the experience. Unfortunately, in our opinion, this ideal situation rarely manifests. More traditional anthropological work (e.g. Mead, 1928) has been criticised (e.g. Freeman, 1999) for reaching inappropriate conclusions, over-interpreting ambiguous data by relying on predispositions, and relying heavily on one or two confederates. Presumably, such criticism may apply to human factors use of the anthropological approach as well. The perspective acquired by the anthropologist is usually not some average controller's perspective, but the perspective of a confederate who has for some reason agreed to serve in that role or who has been assigned, by union or management, to serve in that role. In addition, the confederate may be especially eager to please, providing the anthropologist with evidence that he or she divines would please the investigator.

We have asserted that consulting the controller is a good first step. We also believe that a good second step is to understand the system as deeply as does a good anthropologist. However, we believe that there are other steps on this peripatetic research journey. The other steps take a more traditional scientific perspective, including quantitative tools and experimental methods.

*Ask the scientist?*

Although much applied research has begun to embrace qualitative methods familiar to the anthropologist (see Durso, Nickerson, Schvaneveldt, Dumais, Lindsay and Chi, 1999, for a variety of applied methods), quantitative scientific methods should also be an integral part of resolving the flight progress strip conundrum. The discipline of psychology has adopted the scientific method, complete with quantitative measurement, statistical analysis, and rigorous control, as its epistemological engine. Like its qualitative sister disciplines in the social sciences, the quantitative methods of applied psychology can supply an informed, but objective, viewpoint different from the controller's. In our view, a good scientific field study would not neglect the opinions of the controller or the rigorous study of the anthropologists. Instead, it would build on this foundation by testing, empirically, the hypotheses that emerge from the ethnographic analysis.

The scientific method is not restricted to laboratory experiments, although it is generally accepted that attempts to prove that a variable (e.g. paper versus glass) *causes* changes in behaviour or cognition requires the kind of control one expects in an experiment. Scientific methods allow for naturalistic observations, surveys, and field experiments. However, understanding what is necessary to show causation is a valuable context in which to view these less controlled methods. These other scientific methods, however, typically have more external validity and ecological validity than do laboratory experiments.

Finally, quantitative measurement and statistical procedures are fundamental to scientific psychology. The precision offered by operational definitions and quantitative measurement helps make it clear when a procedure applies and when it does not, when a finding replicates and when it does not, and when something is data and when it is not. Well-trained scientists are also attuned to the need to distinguish empirical data from hypothetical constructs. Although qualitative researchers have argued that scientists also have their pre-theoretical biases (we agree), the problem is greatly magnified in anthropological procedures. We also agree that statistical methods do not guarantee that a conclusion is correct. In fact, it guarantees that there is some probability that it is not. However, statistical methods help to quantify the chances of error: there is a .05 chance that the difference we are reporting is not present in the general population.

Obviously, we suggest asking the scientist about whether or not to replace paper flight progress strips. However, we hope to have made it clear that scientists should begin in consultation with the operator, in our case the controller. They should then study the domain with the rigor of a good anthropologist. However, this study should end in well-reasoned hypotheses—and alternative hypotheses—that are subject to scientific test.

We do not mean to present science as a panacea. For example, science is a slow process. Efforts to generalise findings from one situation to another require several studies. Findings from US en route centres may or may not generalise to US towers or to en route ATC as it is conducted in Europe. In addition, there are situations that do not lend themselves to traditional scientific approaches. For example, the nature of rare events, such as operational errors, makes it difficult to apply quantitative methods. Moreover, while science is exquisite at evaluating different designs, and offers a huge literature on human strengths and weaknesses that one could use to guide design, standard scientific procedures have played less of a role in the actual design process.

Although we believe strongly that multiple methods are valuable, we are not merely advocating an all-inclusive position. We argue that different methodologies and approaches are valuable for different goals. To know the domain you are studying is a valuable lesson and one that is likely to save the efforts of a scientific study that in hindsight yields 'obvious' results. Scientific and anthropological methods provide valuable descriptive tools, but any attempt to go past a descriptive goal is best supported by scientific methods. Here, the question is whether paper flight progress strips are causally necessary to air traffic safety and performance.

## Reasons to switch

Although the current system is incredibly safe, the safety levels enjoyed today are undoubtedly under pressure by the increasing numbers of flights evidenced over the past years and the continuing increases in flights anticipated in the future. Proponents of change argue that the procedures and technology in place today will be inadequate to alleviate the pressures placed on the air traffic system by greater traffic density, the airlines' hub systems, and the flying public's appetite for cheap, frequent flights. The airlines claim to have the technology necessary to make flying more efficient, but that ATC's outdated equipment cannot accommodate the new technologies. The inconvenience of delays witnessed by travellers and covered extensively by the media are the tip of an iceberg that—if nothing changes other than the number of flights—will ultimately compromise efficiency, and perhaps even safety, of air travel. Although terrorists' attacks have temporarily slowed the rise in demand for air travel, the pressures have been mitigated, not eliminated. For example, David Plavin, North American president of Airports Council International, said that airports should continue expansion projects (Fiorino, 2001).

From our review of the evidence, we believe that there are good reasons to switch from the paper flight progress strip to some electronic representation of flight data. People on both sides of the debate seem to acknowledge that the future will bring increasing pressure on the ATC system. Therefore, they agree, something should change. We argue here that changing the paper flight progress strip and its accompanying procedures is the part of the system to change. This is not to say that all automation works the way it was intended; new automation can, in fact, create potential for human error that was not anticipated before the technology was introduced (Billings, 1997). Thus, we argue not for a particular technology, but merely that the target for the new technology should be the paper flight progress strip.

Below, we make six arguments to support our assertion. First, paper strips are a roadblock to future improvements. Second, a modern technology substitute for the paper flight progress strip can make the controller's job easier. Third, the argument that controllers 'like strips' is simply not universally true, although there are clear pressures on controllers, and particularly facility managers, to continue to use strips. Fourth, many reasons for having paper flight progress strips are no longer relevant, even in the current system. Fifth, strips will not supply the functional fit in future environments that they arguably do today. Sixth, we address arguments that paper is inherently superior, that the strip has evolved into an artefact that has attributes other than those for which it was designed, and that strips are indispensable as a redundant backup system. Each of these points will be discussed in more detail over.

*Roadblock to future automation*

If change is required, why focus on the flight progress strip? Currently, not all flight plan information that controllers write on flight strips is entered into the host computer. While controllers enter altitude and route changes into the computer, they do not enter heading and speed changes, nor do they enter minor route deviations (for example, to avoid weather) that would put the aircraft back on the original route before it leaves the sector. However, in order for en route decision aiding tools and communications to have accurate information, the flight data entered into the host computer must be complete, accurate, and up-to-date. If controllers are required to enter accurate flight plan changes and keep up with strip marking, the increased workload of maintaining two data sources will likely introduce errors in one or the other. Thus, retaining paper strips prohibits not merely their automation, but also prevents the introduction of virtually all other intelligent automation aids.

*Reduced workload*

The second reason why paper must be automated is that maintaining two sets of records (by both making strip markings and entering information required by the ATC automation) is a monumental task that could easily overload the controller and reduce the effectiveness of new en route decision aids. The human factors plan for URET CCLD (Crown Communications, Inc., 1999) confirms this assertion. The plan said that controllers at facilities using the test version of URET learned the lesson that trying to use URET while simultaneously maintaining flight strips is not feasible; if controllers are required to maintain paper strips, they do not have the time to use the trial planning capability necessary to achieve FAA's expected efficiency and safety goals. Furthermore, electronic and handwritten flight data may contain different information because one is updated more rapidly than the other, potentially resulting in errors, confusion, and increased workload.

Electronic representation of flight data can reduce, in principle, the controllers' workload considerably. Strip marking requires effort that is often used in record keeping, but that could more profitably be used in separating airplanes and ensuring that flights are more efficient. For example, Albright, Truitt, Barile, Vortac, and Manning (1995) showed that field controllers using the ARTCC's dynamic simulator (DYSIM) who did not have access to flight progress strips spent more time looking at the radar than they did when strips were present. Because most electronic flight data can update automatically, just as information on the radar updates, the controller's workload, at least in some situations, will be reduced.

With modern technology, there are few pieces of information that cannot electronically be gathered, displayed, and transferred to other controllers. The situations that do not lend themselves to such automation (assuming no improvements in voice recognition), such as noting pilot requests that cannot yet be accommodated or indicating clearances that have been issued but not yet responded to, may be addressed in other ways in future automation, or even with a notepad. MacKay (1999) disparages the use of notepads, thinking of them as a backhanded admission that paper strips should be retained. However, there is a difference between noting all possible control actions for all flights and noting the few instances that require a memory aid.

We (e.g. Vortac et al., 1994) have shown that a very large number of the controller's activities are involved in board management responsibilities. If the time and workload saved by eliminating record keeping compensates for any perceived benefits obtained from strips, then removal of the responsibility for marking strips would be reasonable *even if* there were some advantages of paper flight progress strips. Consider, for example, the fact that 'moving' flight progress strips was the most frequent activity in Durso et al. (under review), occurring about seven times a minute. Controllers judged movement as having a benefit. However, controller-judges rated movement as low importance, and in controlled studies discussed below we note that eliminating movement did not influence performance. So, why do controllers move strips? We believe it is because it is an important part of managing the strips themselves. Thus, like a bureaucracy, flight strip management spawns its own infrastructure.

So how can we assume that a perceived benefit is not a real one? The techniques and results discussed thus far, whether qualitative or quantitative, cannot resolve that question. For example, observing that controllers mark on strips cannot reveal the value of marking. Asking controllers why they make a mark tells us what the controller perceives as a benefit, not what benefits are actually observed. The answers to such questions require comparisons against control conditions that differ only along the dimension of interest.

Vortac, Edwards, Fuller, and Manning (1993) presented controllers with simulations of air traffic using high-fidelity en route simulators at the US FAA's ATC training facility in Oklahoma City. The researchers prevented controllers from writing on or manipulating strips by gluing the strip holders together and removing their pencils. Results showed no deficits, and in fact some benefits, in the restricted strip condition. Controllers were able to grant more pilot requests and to grant them sooner, presumably because elimination of strip marking requirements freed time to act on these requests.

Of course, in the Vortac et al. (1993) study, the information on the strips was still visible. Perhaps the lack of impact on performance suggests that strip marking was unnecessary, not that the strips and their data were unnecessary. However, Albright, et al. (1995) removed the strips entirely. The controllers did compensate for the lack of strips by requesting more flight plan readouts from the CRD, but these requests did not hurt performance. Interesting, although some controllers complained that asking for flight plans caused them to pay less attention to the PVD, in fact, controllers spent more time looking at the scope, not less; with strips, 57% of the time controllers watched the radar display compared to 76% when they had no strips.

Finally, Vortac, Barile, Albright, Truitt, Manning and Bain (1996) gave controllers a one-line electronic strip that contained only some of the information normally present on the paper strip. Again, any writing or movement of the strip was eliminated or mediated through the system's input devices. No deficits were observed compared to a condition where traffic was controlled normally. Thus, in controlled experiments, the controllers easily compensated for the lack of strips and did so in such a way as to—if anything—improve performance as measured by indices like granting pilot requests and time-on-scope.

### *Controllers like strips?*

It is obvious that most ATC facility managers believe that paper flight strip usage is essential in all sectors in today's environment because most continue to require controllers to perform full strip marking even though optional strip marking is allowed (Federal Aviation Administration, 2000; Section 6-1-6). One reason that ATC managers may continue to emphasise strip usage, even at sectors with full radar coverage, is that many learned to control traffic using only strips (or the combination of strips and primary radar) and so believe that using paper strips is an essential part of ATC. Many controllers and most managers believe that strips should always be consulted to correlate radar data with flight data and predict potential conflicts before an aircraft enters a sector, while many other controllers prefer to identify aircraft by looking at the data block and predict conflicts by examining the targets on the radar display.

Some controllers prefer to access flight plan information using the computer while others instead prefer to read paper strips. Most of the aircraft information available in the flight plan is also available from the host computer without having to use the strip. For example, controllers may enter a flight plan readout command to view text included in an aircraft's flight plan on the DSR CRD view (window). Another command, the route display, shows a line on the situation display that follows an aircraft's route through the sector.

Whether a controller prefers to use the computer or flight strips to accomplish different activities is a matter of preference (Manning, 2000). Some controllers feel they do not need to use strips, even in today's environment, or feel they do not need to look at them again after an initial examination just before an aircraft enters the sector. Other controllers prefer to glance at the strips to obtain flight plan information rather than make the computer entries required to access the information. Manning (2000) found that two styles described the methods most controllers used to interact with strips—when using one style, controllers de-emphasised marking but looked at the strips occasionally whereas when using the other style, controllers emphasised the traditional role of strips (marking fully and using them to obtain all flight plan information).

Finally, even controllers who would like to eliminate strips have over-learned and extensively practiced flight strip marking behaviours. Controllers are taught and encouraged to use strips throughout their Academy and field training (Federal Aviation Administration, 1998; Appendix 4; Stein, 1994) and part of their OJT instruction/evaluation is based on how well they use flight progress strips (Federal Aviation Administration, 1998; Appendix 2). Accuracy of strip marking is reviewed during periodic over-the-shoulder evaluations and investigations of operational errors always check on whether flight strips were marked properly. Thus, flight strip usage is required, trained, and emphasised extensively in en route ATC.

*Obsolete uses*

It is also important to realise that the strip, virtually unchanged for years, does not serve all the same purposes now that it once did. In the past, because of the quality and availability of radar coverage, controllers would often control traffic manually, that is by using crossing-fixes and estimated times of arrival at those fixes. Today, except in a few parts of the US (e.g. over the Rockies, and in small areas without full radar coverage), controllers rarely control traffic without radar, and thus rarely use some of the information printed on the strip.

The paper flight progress strips also served originally as a legal record should an investigation prove necessary. In fact, in the US most en route centres still follow this directive and require controllers to mark strips: 'to post current data on air traffic and clearances required for control and other air traffic control services' (Federal Aviation Administration, 2001; Section 2-3-1). However, today, most air traffic activity is automatically recorded. For example, system analysis recordings (SAR) record all aircraft movements and host data entries, and audio recordings are made of all pilot/controller communications, communications between controllers working at different sectors, and transfers of position responsibility. The data block contains some information about flight plan updates, such as the assigned altitude. In addition, the identity of the sector that has control of the aircraft is displayed in the data block. Thus, most of the information marked on strips is redundant with other recorded ATC data.

As we mentioned, optional strip marking may be authorised at certain sectors for aircraft that meet certain requirements (Federal Aviation Administration, 2000; Section 6-1-6); however, managers at facilities not currently using URET have chosen not to adopt that option. Instead, most en route facilities maintain extensive localised strip marking orders that specify facility-specific procedures for making strip markings and continue to emphasise the use of flight strips. In part, this is because managers believe that controllers will remember important information about a flight if they write that information on a paper strip.

Some controllers have developed other methods for remembering that they have accomplished certain tasks that do not require writing on strips. For example, the length of the leader line can be reduced to zero after communications for an aircraft are transferred to another sector. In addition, the position of the data block in relation to the position symbol can be changed to indicate that transfer of communications has occurred. If a controller always accomplishes certain tasks immediately (such as coordinating a speed change with the next sector) he or she may not feel it necessary to write down the fact that the coordination has been accomplished. In fact, changes are being made to the host system to increase the amount of flight plan information shown on the situation display. For example, an extra line is being added to the data block that will allow the controller to record issued speeds and headings. When this is accomplished, requiring the controller to write this information on the flight strip as well as enter it into the computer will unnecessarily increase the workload.

### *Anachronistic strips*

The introduction of some technology into a work environment, such as a new radar system, often has consequences on other technologies, such as the paper flight progress strip. For example, the DSR workstation recently introduced in the US en route centres to replace aging equipment reduced the amount of space available to post flight progress strips because the 20' by 20' (508mm x 508mm) display is so much larger than the PVD used previously and the RA monitor is much larger than the CRD used previously. The new flight progress strips for the en route DSR are in fact smaller, reduced from the original 8' x $1^3/_8$' (203mm x 35mm) to $6^3/_8$' x $1^3/_8$' (162mm x 35mm). FAA-sponsored research to investigate whether an even smaller strip could be used (Durso, Truitt, Hackworth, Albright, Bleckley and Manning, 1998), but it was found to be too small for many en route applications. So, the debate about the value of paper flight progress strips was suspended temporarily as stakeholders tried to determine how to change the size of the strip to compensate for the reduced space available while not entirely eliminating the strips or their functionality. If planned procedural changes are implemented, the value of the strip's information will become even less. For example, the US is considering 'free flight,' (RTCA, 1995) a change in procedures that will allow pilots to fly direct routes, and in later phases, may allow pilots to vector (e.g. around weather) when necessary without being told to do so by a controller, in fact without necessarily notifying the controller. In such an environment, information on a paper flight strip will become increasingly useless as the control of air traffic becomes more tactical and less strategic. Although there is some evidence that situation awareness will be compromised in free flight (Willems and Truitt, 1999), there is no evidence about the role of strips.

*Problems with arguments to keep paper*

Arguments to keep paper are of three kinds. One argument is that paper has inherent advantages to glass. A second argument is that the paper flight progress strip has evolved and acquired functionality not anticipated by the original design. These functions are typically thought to be ancillary cognitive functions. The third argument views paper strips as an irreplaceable backup should the electronic system fail.

*Inherent advantages* Researchers have pointed out the disadvantages of screen presentation compared to paper in general (Luff, Heth and Greatbach, 1992). Luff et al. argued that there are five disadvantages of screen presentation compared to paper: 1) Keyboard entries are more difficult, 2) the range of entries is restricted, 3) computer entries restrict the sequence of input, 4) glass representations restrict the mobility of the information through the workplace, and 5) screen displays offer fewer ways of differentiating a document.

Luff et al. have done a nice job articulating problems with glass, but for our purposes the question is the extent to which these issues apply to ATC and, if they do apply, the extent to which concomitant benefits outweigh the disadvantages. Point 1 applies only to the entries that must be made. In ATC, many entries made today are unnecessary for operational purposes. Most entries that are required to be made for operational purposes are already made by keyboard entry; often the strip marking is made in addition to entries via keyboard. Entries studied in controlled research settings (e.g. Albright et al., 1995) that are made only by pen for ancillary purposes may not, in reality, be necessary at all. Thus, although Luff et al.'s first point is well taken, in ATC it is not clear how many additional keyboard entries will be necessary.

In ATC, there are sometimes advantages to restricting the range of entries (point 2); this need for restricted range of entries manifests even with paper strips: Many facilities have their own strip-marking guides to help standardise marking.

What seems critical from point 2 is, not that entries will be restricted with glass, but that they will be restricted inappropriately. It is important that entries be developed to take into account the important functions needed in flight data representations.

Point 3 would be highly dependent on the particular software implementation. If, and it is a big if, all of the electronic representations can be presented on one screen, problems with paging and sequential entries can be eliminated. In ATC, although the tasks are performed in the order the controller prefers, evidence exists that interacting with the paper flight progress strips is already treated as a separate 'board management module' (Vortac, 1993); Vortac and colleagues showed that controllers waited until the activity slowed down to update the strips, and then did so in a burst of strip activity.

Moving information around the workplace (point 4) is actually quite difficult now with paper strips. The mission critical nature of ATC minimises occasions when information on the strip can be passed hand-to-hand. Once information is represented electronically, this concern should be reduced. At a critical level the fifth point, differentiating aircraft, can be argued to be of little concern given that the radar display distinguishes aircraft spatially. Overall, applying general concerns about paper to the ATC domain suggests that the abstract limitations of glass will not apply.

*Evolution of strips* Arguments that are more particularly addressed at flight progress strips exist in the literature. Many of these arguments derive from the suspicion that the flight progress strip evolved over the years to meet demands of the ATC task that may not have been part of the original design. There is some evidence to warrant such a concern. Research has shown that designers of a high-tech, electronic device intended to replace a low-tech device that has evolved over many years of use, can miss the nuances provided by the older device. For example, the speed bugs associated with the airspeed indicator of the MD-80 have been used in ways never intended in the initial design process. Redesigning an indicator that did not realise these other uses would prove problematic and inferior to the device it replaced (see Hutchins, 1995).

Opinions of controllers often fuel this concern. Even in our data (Durso et al., under review) the comments made by controllers suggest particular benefits. Although controlled laboratory work that we have discussed indicates that some of these opinions about the beneficial functions of strips do not seem to have an impact on performance. As an example, while controllers who did not have access to strips (Albright et al., 1995) thought they were important, their performance suggested otherwise. Thus, while the possibility exists that an artefact could have evolved ancillary cognitive value that aids performance, there is no evidence that flight progress strips are that type of artefact.

MacKay (1999) notes that when she visited a facility that had eliminated strips, paper was nevertheless used throughout the facility. When we visited a facility in the US that was using a decision aid that provided electronic flight data representations, there was no apparent use of paper. However, our visit over a two-day period was not to assess the use of paper, and so we too have no quantitative data.

Finally, the Vortac, Edwards, Fuller and Manning (1993) study mentioned earlier employed several cognitive measures to test directly the speculation that controllers who could not interact with strips would suffer performance deficits because of underlying cognitive deficits. It has been proposed that potential deficits in cognitive processing could occur as a result of automating flight progress strips (Hopkin, 1991; Isaac and Guselli, 1996). For example, Isaac and Guselli (1996) suggested that writing information on a flight progress strip (and recognising that they have written something) reinforces controllers' working memory. Moreover, physically manipulating strips should facilitate both memory for and understanding of the information contained there. And physically interacting with strips should improve prospective memory, which is remembering that something needs to be done in the future.

Not only did Vortac, Edwards, Fuller and Manning (1993) find no performance decrement, but neither were cognitive measures of attentional engagement, visual search, radar recall, flight progress strip recall, and planning affected. The only cognitive measure affected was one of prospective memory, and that one was facilitated when the controller did not have to interact with the strips.

*Backup issue* Strips provide a hard copy backup in case of a system failure at the facility level; a failure so severe that the first-line backup system, DARC, is also knocked out. The notion that the paper flight progress strip is the last barrier to disaster after a power failure may be overstated. One controller, when asked about the strips as a backup for outages, replied that there would be chaos with the strips as well. In some power failures, neighbouring centres have expanded their coverage to handle the affected area. During some types of failures, communications are terminated so it would not matter whether or not strips were available. In addition, the main reason for needing strips during a system failure is simply to be able to identify the aircraft under control of a sector, and *not* to provide extensive ATC services. An electronic system that represents the last known state of the airspace could be maintained on the display by an alternative battery backup. Thus, we see the backup issue as one that can be easily solved once a decision is made about the future of the flight progress strip, yet it may be this backup issue that drives the decision about the future of the flight progress strip.

## Making the transition

It might be argued not only that the switch to electronic representation of flight data is prudent, but also that it should happen sooner, rather than later. First, it seems only reasonable to take advantage of the advances in information technology when old machines (and software) are replaced with new ones. Second, some groups encourage the reduction of paper flight strip usage now, in anticipation of new technologies. Indeed, if reliance on flight strips is reduced now, it might be easier for controllers to adopt new habits regarding the use of electronic flight data in the future. Finally, we note that in the US, the controllers hired in 1981 after the President's dismissal of the Professional Air Traffic Controllers Organization (PATCO) controllers who went on strike are reaching eligible retirement ages and many will be eligible to retire within a decade.

From this perspective, the question is not whether flight progress strips will be replaced but rather how can those who are resistant to change among the US controller workforce be persuaded to accept the change? Outside the US, change may be even more contentious. MacKay (1999) relates the fact that French controllers demanded and received a bonus for using a keyboard to enter modifications in flight plans. She relates (from a dissertation by Poirot-Delpech, 1991) that one controller put it this way: 'If we had not received something interesting in exchange, we never would have done it.'

Of course, a critical part of the transition will be the development of a system that effectively supplies the controller with the information needed. The new representation of flight data may, but need not, looks like a glass version of the paper strip. It might range from a copy of today's flight progress strip, to a one-line flight plan entry, to a time-accelerated projection of aircraft positions on the radar screen, to representations that have yet to be imagined. Input into the new system may range from standard keyboard/trackball entry to provocative ideas like MacKay's (1999) idea to use paper-like input to entry methods that resemble controllers' physical movements (e.g. Mertz, Chatty, and Vinot's, 2000, Digistrips interface) to voice recognition. We turn now to characteristics that are likely to be part of the replacement.

### *SPIN*

We are developing a theoretical abstraction of the flight progress strip replacement system that we have named SPIN. The Shift from Paper Information envisioned to be necessary over the next decade must take place in an informed and cooperative environment. The motivation behind SPIN is not to replace paper flight data representations in the far future, but merely to aid in the design of a transition system, one explicitly designed to allow the socio-cultural transition to proceed. Although we do not have the complete picture, we do have pieces to the puzzle. We know what, technically, the capabilities are of present day computational systems. We also know, based on the results of scientific research, the important actions, the ones that are taken frequently, the operational value those actions, and their cognitive/behavioural benefits as perceived by today's field controller. If it is premature to rip strips from the controller's hand, then the decision makers should take these pieces of the puzzle into account and build a transitional electronic flight data system.

SPIN assumes that transition may be slow, primarily because of the current workforce's history with paper strips. Transition should take place in phases, eliminating those aspects of flight progress strip use that are redundant or anachronistic based on available research. Thus, consideration of prior studies, temporal patterns of marking, and controller comments all lead SPIN to suggest that a reduction in strip marking should precede a reduction in strip availability. SPIN has many other specific components that derive directly from the scientific work. As examples, if automation is applied to the strip markings/actions believed to be important during the strip observation study (Durso et al., under review), then four categories of markings (issued clearances, coordinated clearances, non-clearance co-ordinations, including pointouts, and information updates) should be addressed first. One strategy for automating these markings is to determine how best to accommodate their perceived benefits, regardless of whether or not these perceptions are accurate.

For instance, if a mark is perceived to benefit memory, then it is necessary to display updated flight plan information as changes occur so the controller can examine the information as needed and not have to remember it. To determine whether flight plan information is accurate and ascertain how the flight plan has evolved, it may be necessary to view a history of clearance changes. This history does not need to be displayed all the time but should be available to observe only when needed. As another example, electronic representations that benefit communications must emphasise information that a team member can detect easily, without requiring much interpretation. SPIN suggests that the automation replacement be placed at the workstation between the R and RA controllers, allowing the communication benefits of the flight data representation to manifest most directly, thus improving communication and reducing workload.

Reducing workload further can occur with a reduced number of message entry methods. Both team members should be able to update the information to support different strip marking procedures used at different facilities. Specifically, at some facilities the R controller marks the clearances that he/she issued while at others, the RA controller marks the clearances that the R controller issued. Because these facility differences are real in the transition workforce, SPIN emphasises that a strip replacement should be flexible enough to accommodate both methods of recording issued clearances rather than requiring controllers at one facility to change the way they do business at the same time that they have to change the way they record strip markings.

Combining electronic methods that support specific strip markings having multiple perceived benefits will be more complicated. For example, in the strip observation study, markings concerning issued clearances were perceived to benefit memory, communications, organisation, and reduced workload. To support all these benefits, an electronic representation should be visible to all team members, display current flight plan information, have an available history that can be examined if necessary, be easy to enter, and support modification by all team members.

At the same time, a paper backup, such as a notepad can be used to write down specific information that is inconvenient to record electronically, and can be used to highlight information that needs to be emphasised to the other team member. SPIN requires that some flight data representation survive a power failure, suggesting the need for automation with battery backup for a last-position display.

## Conclusions

This paper has considered research and opinions concerning both the need to eliminate paper flight strips and the need to retain them. If ATC automation enhancements are to be realised in the future, it will be necessary to supply them with increasingly specific and accurate data regarding an aircraft's position and any clearances that have been issued. Although aircraft positional data can be provided by surveillance methods (radar, ADS-B), clearance information must be provided by the controller. If controllers are required to maintain two data sources by entering clearance information into the computer and maintaining the same information on paper flight strips, the result will be increased workload and increased likelihood of error (in one source or the other). Thus, we must get rid of paper because writing on strips will not support the goal of maintaining an accurate database for the automation's use.

However, today, many controllers, especially those in management, strongly believe that it is necessary to retain flight strips. At present, there is no universally accepted method for performing the same functions supported by strip marking without the use of paper strips. Consequently, some controllers have developed short-cuts (such as accessing the aircraft type using the flight plan readout function of the current computer system) or cues (such as setting the length of the leader line to 0 after transferring communications for a flight to the next sector) that they believe sufficiently replace important functions of strips. However, other functions, such as making a check mark next to the altitude when a pilot checks on a frequency, or circling a clearance when it has been coordinated, cannot be duplicated using the DSR system and, thus, a controller who does not mark strips must somehow remember that he/she has accomplished these tasks. Some controllers and managers believe it is always necessary to record this information on strips whereas other controllers feel confident in their ability to remember all the relevant information.

Another concern regarding the elimination of paper strips is what happens when the system goes down or the power goes out? Although backup systems significantly reduce the likelihood of a failure that would result in a facility-wide blackout of radar displays while leaving communication capabilities intact, the possibility of such a failure remains, and such failures have occurred occasionally.

So, should flight progress data be spun from paper into glass? Most of the research indicates that no performance impairments would occur and some performance improvements would be realised. In addition to laboratory work, operational use of URET has resulted in general acceptance of the tool as a strip replacement. It might be argued that the research is based on laboratory studies having limited generalisability, and the operational use occurred at centres that may have different types of operations than some other centres in the US. Certainly, additional testing in specific environments would be prudent (sectors having partial radar coverage, providing approach control services, or where extensive holding occurs). For example, in Durso et al. (under review), weather happened not to be a factor during the observations raising the concern that holding, which accounted for less than 2% of the marks, was underrepresented. It would also be reasonable to place controllers in different situations under controlled conditions. For example, in Albright et al. (1995) controllers were not required to pass information (i.e. headings and speed) to another sector. Therefore, this communicative function of strips may not have been stressed. Additional research addressing issues such as the appropriate location of displayed information (on the situation display as opposed to an auxiliary display) would also be of value. Currently, however, there is no scientific or operational evidence that suggests that automation of flight data will have negative consequences.

The immediate issue, however, is not whether glass will ultimately replace paper, but how the transition necessitated by socio-cultural factors should proceed. While some feel it is desirable to reduce or eliminate the use of flight strips in anticipation of new technologies (in order to break the habit before controllers are introduced to a new tool), others, including most managers and some controllers, are reluctant to reduce their usage before an electronic flight strip replacement becomes available. As a result, not all strip replacements will be found acceptable. Moreover, of course, the issue of what to do when the power goes off is still under discussion. Well-motivated changes in procedures as well as an electronic strip replacement that incorporates the important functionality of strips will be important parts of a transitional environment for the current workforce.

It is clear the implementation of advanced tools, technology, and associated procedures necessary to replace paper flight strips is a complicated and important issue. It is also clear, however, that viable solutions will require the subject matter knowledge of the expert controller and the scientific knowledge of the aviation researcher.

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