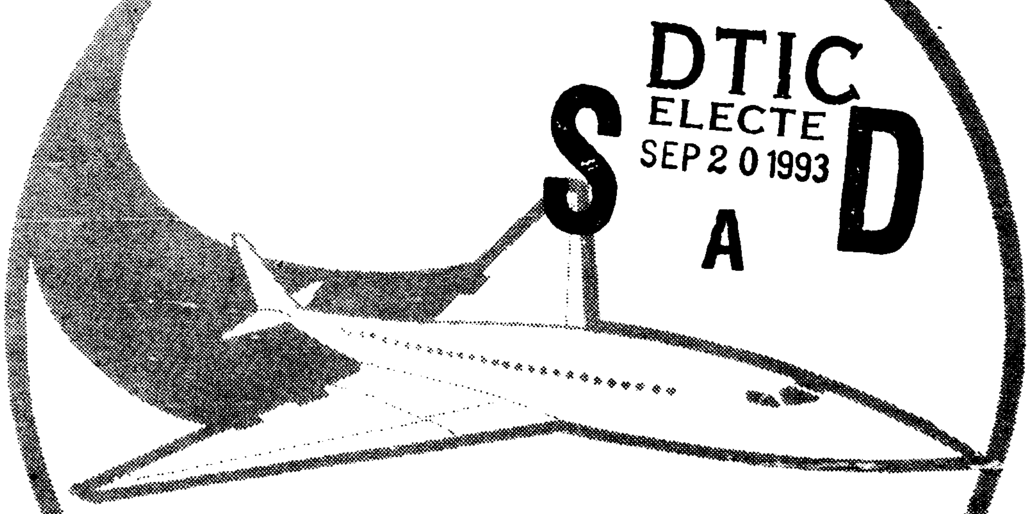
Influence of Individual Experience and Flight Strips on Air Traffic Controller Memory / Situational Awareness



June 1993

DOT/FAA/CT-TN93/31

U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

technical note technical note

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN93/31	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Influence of Individual Experience and Flight Strips on Air Traffic Controller Memory/Situational Awareness		5. Report Date June, 1993
		6. Performing Organization Code
7. Author(s) Carolina Zingale, PhD, Stan Gromelski, S. Basheer Ahmed, PhD (PERI), and Earl S. Stein, PhD (ACD-350)		8. Performing Organization Report No. DOT/FAA/CT-TN93/31
9. Performing Organization Name and Address PERI (Princeton Economic Research, Inc.) 322 Wall Street Princeton, New Jersey 08540		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA03-89-00050
12. Sponsoring Agency Name and Address Federal Aviation Administration Technical Center Engineering, Research, and Development Service Atlantic City International Airport, NJ 08405		13. Type of Report and Period Covered Technical Note June 1992 - February 1993
		14. Sponsoring Agency Code ACD-350
15. Supplementary Notes		

16. Abstract

An experiment was conducted to compare situational awareness and control ability between two test conditions. One condition allowed for the active organization of aircraft information (allowed note-writing on flight strips containing directional arrows). The other did not (note-writing not allowed, no arrows on strips). Such flight strip management activities have been cited as critical for the formation and maintenance of the controllers' "picture."

Participants were eight air traffic controllers with at least four years of on-the-job experience. They were tested using TRACON II, an air traffic control (ATC) simulator for the personal computer (pc) which requires keyboard-entered, rather than verbally-issued commands. Situational awareness was evaluated during intervals in which each of the test scenarios was paused and the display was blocked from view. Participants indicated the locations of all active aircraft on a paper map and reported the last command issued to each. Control performance was evaluated using a variation of the TRACON-provided scoring system.

Situational awareness and control performance did not differ as a function of test condition. However, situational awareness was found to differ as a function of reported level of video-game experience. Controllers who reported lower levels of video-game experience on a pre-test questionnaire, showed improved situational awareness when they were allowed to write on the strips. Those who reported higher video-game experience maintained higher situational awareness across both conditions. Further analyses indicated that these groups differed in terms of their memory for last-issued commands (and more specifically, for last-assigned altitudes), not their memory for aircraft locations.

Regardless of video-game experience, controllers reported that their ability to remember call signs in this experiment was lower than it is on the job. Having to issue commands via the keyboard, instead of verbally, may have produced this result. The implications of these results for systems requiring such interaction are discussed.

17. Key Words Air Traffic Control, Controller Memory, Situational Awareness, Memory Enhancement, Flight Strips, Note-writing		18. Distribution Statement Available to the public through the National Technical Information Service Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 73	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ACKNOWLEDGMENTS

We gratefully acknowledge the participation of controllers from the FAA Technical Center and the Atlantic City International Airport, who volunteered their time and effort to support this project. We would also like to thank the non-controller participants who took part in pilot work on this project, employees of the FAA Technical Center and students from the Aviation Program at Mercer County Community College, West Windsor, NJ.

EXECUTIVE SUMMARY

Situational awareness and control ability were measured under two test conditions using a low-fidelity, personal computer (pc) based simulator (TRACON II). Unlike the actual air traffic control (ATC) environment, TRACON II requires that commands be issued via keyboard, rather than verbally. Participants were air traffic control specialists (ATCS) who were either current or former controllers with experience in terminal environments. The purpose of the experiment was to determine the impact of note-writing and flight strip organization on situational awareness and performance. A secondary purpose of the experiment was to determine the efficacy of using this type of simulator to conduct research with air traffic controllers.

In one test condition, participants kept notes on flight strips that included arrows indicating whether aircraft were arrivals (↓), departures (↑), or overflights (↔). In the second condition, note-writing was not allowed and arrows were not presented. Situational awareness was measured by stopping the scenario, blocking it from view, and requiring participants to record the location of each active aircraft on an airspace map and to report the last command issued to each.

Participants also completed pre- and post-session questionnaires designed to identify other factors potentially relevant to performance, such as level of ATC experience, computer or video-game experience, motivation to participate, stress level, and workload level. Participants also described their control strategies and indicated anything that they felt had helped or hurt their performance in the sessions.

Neither situational awareness nor control performance differed significantly between test conditions. However, situational awareness did differ as a function of the participants' level of reported video-game experience. Those reporting a higher level of video-game experience performed equally well under both test conditions. In contrast, those reporting a lower level of video-game experience did more poorly when note-writing and directional arrows were not available. Their performance improved significantly when these organizational tools were available.

Further analysis revealed that participants who reported lower video-game experience differed from those reporting higher video-game experience with respect to memory for last-issued commands, but not memory for aircraft locations. Memory for last-assigned altitudes was specifically investigated since controllers typically record altitude changes on strips. The same pattern of results was obtained. Participants with lower video-game experience showed poorer memory for altitude changes than did those with higher experience, particularly when note-writing was not allowed. Flight strips may have been helpful to the group with low video-game experience because strip marking provided a means by which aircraft information could be kept up-to-date while attention was devoted to the task of manually issuing commands and receiving visual feedback.

An additional important finding was that, regardless of their level of video-game experience, participants believed that they were less able to remember the call signs of aircraft in this experiment, in which control commands were typed, than they are on the job, in which commands are issued verbally. Participants recalled an average of 82 percent of call signs in this experiment. One participant recalled only 20 percent. This is important since it suggests that critical information may be lost under conditions in which keyboard entries are used to communicate with aircraft. These results may, therefore, have important ramifications for systems requiring keyboard rather than verbal communication.

Several important implications emerge from this research: 1) Controllers' performance with certain ATC systems may depend upon the amount of prior experience they have had with complex systems, like video-games, which require rapid decision making and skilled eye-hand coordination, 2) Memory lapses and effective memory-aiding techniques may differ between different subgroups of controllers depending on their knowledge of and skill level with various systems, 3) Results of research conducted with low-fidelity systems can not be directly translated to the present ATC environment. Although controllers were willing and able to use a low-fidelity system, testing must eventually be conducted in an operational environment because no simulation completely models the actual system.

1. INTRODUCTION.

1.1 PROLOGUE.

Air traffic control (ATC) began as an essential response to increased demands on the airspace. During the early years of ATC, prior to and including World War II, controllers directed traffic using only the flight plans of aircraft and a clock. Controllers had to experiment and work out methods of managing their responsibilities. They had to scan flight plans to gather information, organize the information in order to make decisions and plan courses of action, and remember their plans and actions along with other critical information to maintain separation and expedite the flow of traffic.

Technological advancements continue to be made to meet the ever increasing demands for service. Numerous hardware and software tools have been developed to improve the safety and productivity of the ATC system. Yet, despite all the automated and semi-automated aids available, controllers must still make use of the same skills they relied on previously. They must still plan, organize, scan, decide, and remember.

The ATC system remains very centered on the human controller. While controllers add flexibility and adaptability to the system, they also add the potential for error, as Senders and Moray (1991) have described,

> "All of us have experienced human error. When we interact with machines or complex systems, we frequently do things that are contrary to our intentions. Depending on the complexity of the system and the intentions of the people interacting with it, this can be anything from inconvenience (often it is not even noticed) to a genuine catastrophe" (Senders and Moray, 1991, p.1).

Identifying the human's role in the system and the potential causes of human error is, therefore, critical in order to enhance system safety and efficiency.

An administrator's task force (Operational Error Analysis Work Group, 1987) studied the frequency and possible reasons for operational errors in ATC. An operational error represents a mistake made by a controller which fortunately leads, in most cases, only to a minor violation of airspace separation standards. The task force identified visual scanning and memory as two major categories of errors. The latter is the focus of this report.

Memory requirements in ATC are demanding. Air traffic controllers are surrounded by sources of information from which they must select the most critical components. They must then code and store this data. However, this is not always done effectively. One of the most common expressions uttered by controllers who have made an operational error is: "I forgot!".

When a memory lapse occurs, critical information about aircraft (e.g., location, heading) may be temporarily unavailable. Without ready access to such information, situational awareness may not be adequately maintained and a crisis may result. It is essential to understand memory lapses and the circumstances under which they occur so that effective training procedures and strategies for managing memory can be developed to assist the controller.

In 1991, there were 701 controller operational errors in the United States (FAA, 1992). While this is promising in that it represents a reduction from 872 errors the previous year, the Federal Aviation Administration (FAA) is constantly striving to eliminate any such errors. Efforts to enhance controller memory are designed to assist the FAA in reaching this goal.

1.2 BACKGROUND OF ATC MEMORY RESEARCH.

Kinney, Spahn, and Amato (1977) analyzed FAA reports and developed 8 categories of errors which included: controlling in another's airspace, timing and completeness of flight data handling, inter-positional coordination of data, use of altitude on the display, procedures for scanning and observing flight data, phraseology and use of voice communications, use of human memory to include relying on recall in a noisy environment, and dependence on automatic capabilities.

The FAA uses a somewhat different set of categories to classify operational errors. In the profile of operational errors for 1987, the following categories were employed: radar display, communication, coordination, aircraft observation, data posting, and position relief (FAA, 1988). By far the most frequent source of errors identified by the FAA was in a subclass of "radar display: the misuse of data." It is likely that memory issues played a role in these data-induced errors.

The rate at which information flows through the ATC work station cannot be completely controlled (Sperandio, 1971; Kirchner and Laurig, 1971; Thomas, 1985). Controllers must, therefore, be able to manage memory successfully in order to select and retain all of the critical elements that confront them. It is essential to establish a clear understanding of controller memory especially as new hardware and software systems are developed. As automation increases, the flow of information is likely to increase, placing an even heavier burden on controller memory.

The amount of information and the speed with which it can be processed are limited (Finkleman and Kirchner, 1980; Spettel and Liebert, 1986; Warm and Dember, 1986). Opinions concerning the extent of human limits have varied considerably. Miller's (1956) concept that we process about 7 (plus or minus 2) chunks of information at any one time has become accepted doctrine, despite the fact that evidence has shown otherwise under certain conditions (e.g., Klapp, Marshburn, and Lester, 1983). The "7 plus or minus 2" view may be too restrictive for static memory, on which it was based, and may be too optimistic for dynamic memory (Moray, 1986).

It is likely that actual working memory is a multi-operational system which includes static memory, dynamic memory, and attentional components (Baddeley, 1986).

Working memory for the controller certainly includes a dynamic component. In order to manage aircraft, information must be captured and retained for tactical use (3 to 5 minutes) and, secondarily, for strategic planning. Each aircraft's call sign, type, route, and so forth, must be retained for as long as it is under an individual's control and then discarded. While under control, other information (e.g., altitude, speed, direction, etc.) must be continuously updated and readily accessible so that separation of aircraft can be maintained. Controllers' memory requirements are further burdened by inclement weather or emergency situations since these may require deviations from the usual expected courses of action.

In today's ATC system, one of the principal tools that controllers employ to keep information up to date, is the paper flight strip. Controllers are required to annotate these strips with changes that they make to the flight plans along with other operational considerations (FAA, 1989). In addition to writing notes, controllers often rearrange strip placement to act as reminders as to what they have done with aircraft and what they will need to do in the future. The important connection between flight strips and air traffic controllers' (ATCSs') memory has been noted by Vortac (1991). This report indicated that "memory is essential in understanding the relationship between flight progress strips and ATCS performance. However, the relationship may not be immediately obvious."

The value of flight strips has recently been addressed by a study conducted by researchers from the Civil Aeromedical Institute, the University of Oklahoma, and the FAA Academy (Vortac, Edwards, Jones, Manning and Rotter, 1992). The authors noted that, although controllers often view flight progress strips as unimportant, they do use them. Their study focused on controller behavior in a simulated en route environment and found that note-writing on strips was one of the more frequent activities that controllers engaged in. This group found that as controllers became busier in higher-complexity scenarios, they fell behind in updating the strips. Further, controllers increased the number of requests for information from pilots in higher-complexity scenarios, implying that they could not remember or retrieve all the data they needed.

One important aspect of flight strip management is that it allows controllers to organize information, enabling it to be recalled more efficiently. The important relationship between organization and memory has been widely reported in the psychological literature. Bower, Clark, Lesgold, and Winzenz (1969), for example, found that more words were remembered at time of test if they were initially presented according to an organized framework, such as by category (e.g., metals, stones), than if they were presented randomly. Benefits are also observed when the organizational scheme is self-imposed. Those who organize information more extensively have been found to recall more items at time of test than those who organize less (Tulving, 1962).

Means, Mumaw, Roth, Schlager, McWilliams, Gagne, Rosenthal, and Heon (1988) studied the way that en route controllers organized aircraft. They observed that controllers recalled aircraft in groups, invariably drawing one group at a time when tested. When asked to name the groups, controllers labeled them in accordance with a specific type of traffic issue (i.e., arrivals or crossing traffic at a specific fix). Geographical proximity played less of role in grouping than did the interaction and potential conflicts between members of a group. Organization of information has been identified as the one factor which has the greatest probability of improving memory performance in ATC (Vortac, 1991).

Activities like note-writing and other flight strip management techniques (e.g., rearranging) may be important to memory for another reasons as well. There is a finite possibility that motoric enactment, the physical manipulation of something like flight strips, may be the key to remembering future planned actions. Memory for anticipated actions, or prospective memory, is a critical component of ATC, however, very little research has been accomplished which sheds any light on it.

Benefits of physical activity on memory have been found in other domains. Koriat, Ben-Zur, and Nussbaum (1990) and Zimmer (1986) each found that performing action phrases such as, "tear up a sheet of paper" and "blow up the balloon," enhanced recall of those phrases. Memory for phrases whose actions were only imagined was not as high. Activity may involve a deeper level of processing, making information more memorable and accessible, as Norman (1992) recently indicated. By comparing drawing to taking a picture of a scene, Norman described that, "the act of drawing requires a degree of concentration and study that intensifies the experience (p. 8)".

As changes in technology occur, the human operator's role in the system will be altered. In more automated systems, it is likely that paper flight strips will be eliminated and replaced by electronic media. It has been duly noted that the impact of automating the tasks currently undertaken with paper flight strips must be determined, since their value has been so widely emphasized (Garland, Stein, Blanchard, and Wise, 1992). Hopkin (1991), writing about future automated systems, commented that paper strips may well serve beyond their original intended purpose. Hopkin (1991b) has suggested that strip management activities assist in the maintenance of situational awareness, help controllers remember performed and to-be-performed actions, and also help controllers plan strategies for directing traffic (Hopkin, 1991). The proposed removal of paper flight strips has raised the concern that controllers will be more likely to lose situational awareness since active involvement with them will be eliminated (Hopkin, 1991a; Jackson, 1989).

1.3 MEMORY RESEARCH PROJECT AT THE FAA TECHNICAL CENTER.

The memory research program began in 1988. The goals of the program were to conduct research to more fully examine the factors affecting controller memory and to identify and develop memory aids that would assist controllers on the job. One of the initial efforts in this program was conducted by Vingelis, Schaeffer, Stringer, Gromelski, and Ahmed (1990). They examined theoretical concepts of memory and identified a workable cognitive model for controllers that encompassed memory issues. Vingelis et al. adapted a model originally developed by Rasmussen (Rasmussen, 1987; Rasmussen and Lind, 1982), which involves levels of functioning from skill-based to knowledge-based domains. Each of these domains has its own unique sources of memory-induced error. Further, Vingelis et al. defined controller short term or working memory in terms of its functional requirements (including attention and rehearsal), its contents, organizational structure, operational capacity, and limitations.

Another component of the memory project involved the development of the Controller Memory Handbook (Stein and Bailey, 1989). This document was created based on the memory literature as applied to person-machine systems. It was tailored to ATC primarily through the skill of the co-author, Jim Bailey, who, in addition to being an artist, was also an air traffic controller. This handbook combined text and cartoon graphics in an attempt to transfer some key principles of memory to the controller community.

As a follow-up to the Controller Memory Handbook, copies were sent to a selected number of facilities along with an evaluation questionnaire. The questionnaire had two parts. In the first part, respondents were asked to rate the handbook. In the second, respondents were requested to describe how they handled memory on the job in their facilities. Results indicated that personnel liked the handbook and found it useful, although some controllers felt that it was too basic to meet their needs. An even more significant finding was the willingness controllers expressed for stating both the nature of their problems and the techniques they used to deal with them (Stein, 1991).

Respondents identified the following causative issues: coordination, attention, distraction, fatigue, change, overload, and position relief briefings. There was some overlap between these results, those of Kinney, Spahn, and Amato (1977), and those reported by the office of aviation safety (FAA, 1988). Controllers offered many tools they said worked for them to reduce the probability of memory lapses. Most of these centered on what they would call "good housekeeping." This implies the use of effective organizational skills and consistent adherence to procedures, which controllers are theoretically taught to do but do not always do in practice.

In order to pursue these issues in more depth, a two step research procedure was instituted in 1991 (Gromelski, Davidson, and Stein, 1992). The first step of this procedure was a mail survey of facility managers. This was followed up by face-to-face interviews with 170 controllers at facilities across the continental United States. The advantage of interview over survey is that the interviewer can probe and follow up on issues that may be short-changed in a survey approach. One of the most significant findings of this study was that controllers were aware of the memory issues and of the aids available within the system as it exists today. However, they resist using them for the same sorts of reasons that lead them to be reluctant to ask for help if they are overloaded. This somehow violates the controller culture. Controllers did indicate that flight strip management activities, including flight strip organization (cocking, tilting) and marking (keeping notes), were the most used memory-aiding techniques. They also agreed that good controllers engage in certain desirable behaviors. Good controllers were reported to preplan actions, prioritize work sequences, organize aircraft information, anticipate future states or problems, and use effective communication.

Zingale, Gromelski, and Stein (1992) examined some of these concerns in a laboratory setting in which systematic control was possible. These were the first experiments in a series leading to the research described in this report. Zingale et al. worked with college students who were studying to be pilots and had no background in ATC. They were taught the principles of control and were tested using a personal computer (pc)-based simulation, TRACON II. TRACON II was originally designed as a computer game, and part of the purpose of these studies was to evaluate the feasibility of using it as a tool to study control performance and memory issues.

In one experiment, participants were either encouraged or discouraged from developing operating strategies in advance of controlling traffic. Results indicated that this had little impact on performance. In a second experiment, the availability of planning time prior to working simulated traffic (2 minutes vs. 5 minutes) was tested. This also did not make a difference.

In a third experiment, participants were tested for recall of critical flight information after being given the opportunity to mark flight progress strips. Participants were instructed to record the commands they issued to each aircraft on flight strips as each command was executed. Performance was also monitored as participants proceeded through the test session and an overall performance score was obtained. To test memory for critical information, the flight strips were removed at the end of the session and participants were instructed to report all of the commands they had issued to each aircraft. Some participants used flight strips more extensively than others, recording all or nearly all of the commands issued, while others recorded only a portion of them. It was found that those who wrote more on the strips remembered more commands and also performed better. In addition, those who wrote more on the strips reported lower workload levels than those who wrote less. It was recognized that the decision to write or not may well have been associated with what each participant brought with him/her to the study, including basic abilities and self confidence. One of the most noteworthy findings in this series of experiments, was that the potential for using low-fidelity PC-based ATC simulations in testing was demonstrated.

Since the results of the third experiment suggested that flight strip management may be important to memory and performance in ATC, an additional experiment was conducted to evaluate the effects of note-writing and flight strip organization on situational awareness and control ability with actual air traffic controllers. (Further pilot work was also conducted with non-controllers prior to this. The results of this work are described in appendix A. The apparent differences between the results obtained for controllers and non-controllers suggests that research on ATC issues with non-controllers must be interpreted with caution. Data from non-controllers alone may not adequately reflect the performance characteristics of controllers, and may lead to incomplete or inaccurate conclusions.)

2. EXPERIMENT: USEFULNESS OF FLIGHT STRIPS (NOTE-WRITING AND ORGANIZATION) TO SITUATIONAL AWARENESS AND PERFORMANCE.

2.1 PURPOSE.

The purpose of the current experiment was to determine the usefulness of note-writing and flight strip organization to controller situational awareness and control ability. Maintaining situational awareness involves the ability to access critical information about aircraft, such as aircraft location and current status (e.g., altitude, speed). A loss of situational awareness, forgetting about an aircraft or what actions need to be taken, can result in severe consequences such as separation conflicts or crashes.

The results of a prior experiment, described above, indicated that note-writing on flight strips was associated with improved memory for critical information (i.e., commands issued) and improved ATC performance (Zingale, Gromelski, and Stein, 1992). The current experiment further investigated the effect of flight strip manipulation by investigating note-writing and strip organization on control performance and situational awareness. In addition to keeping notes, participants in this experiment were provided with arrows on flight strips indicating that aircraft were either arrivals (↓), departures (↑), or overflights (↔). These were included to provide an additional tool to assist participants in their organization of the aircraft. Situational awareness was assessed by testing each participant's knowledge of aircraft position and the last command issued to each.

2.2 METHOD.

2.2.1 Participants.

Participants consisted of air traffic controllers from the FAA Technical Center and the Atlantic City International Airport Tower. They were assured of complete anonymity. A total of 8 controllers, 6 from the tower and 2 from the Technical Center, participated. All of the participants had at least 4 years of ATC experience in a terminal environment (mean=10.38, standard deviation (SD) = 5.63). Three of them reported having prior experience with the TRACON. All of the controllers had worked with flight progress strips on the job, and used strip board management techniques routinely, although some expressed that they used the strips reluctantly. Participants received overtime pay for their participation.

Participants rated themselves (1=lowest, 10=highest) in several areas that were thought could potentially relate to performance. Controllers rated themselves low in terms of computer experience (mean=3.38, SD=2.39) and video-game experience (mean=3.75, SD=2.12). Levels of reported vision (mean=9.63, SD=.74) and health (mean=10.00, SD=0) were high. Controllers also indicated that they freely volunteered to participate (mean=10.0, SD=0), but varied in their motivational level (mean=3.38, SD=3.54). (The question on motivation was worded so that a response of 1 was highest and 10 lowest). Stress levels for this group were generally low to moderate (mean=4.25, SD=1.67).

2.2.2 Equipment.

The TRACON II ATC Simulator for the IBM PC (Wesson and Young, 1990) was used in testing. Simulations were run on 486 computers at the Human Factors Laboratory of the FAA Technical Center. TRACON II is capable of presenting aircraft in sectors surrounding major terminal control areas like Boston, Los Angeles, etc. The areas represented are limited only by the need for site-specific data. Sector, number of aircraft, weather conditions, pilot performance, equipment, and number of potential emergency situations can be specified by the user. Scenarios can be generated randomly by the game itself or specifically programmed. Programmed scenarios were used in this study to control for the variability that different scenarios may produce.

Programmed scenarios were created using the DOS editor as described by the TRACON II manual. In each of these scenarios, the number of relevant airports and fixes within the sector was reduced so that participants would be able to learn the names and locations quickly, enabling training to proceed more rapidly. The Los Angeles sector, including two of its five airports (LAX and Long Beach), and 7 of 15 outer fix locations, was selected. Weather and equipment were set to "perfect". Pilot performance was set to "average" for smaller aircraft, so that participants would have to pay attention to readbacks to ensure that commands had been accepted. Aircraft were included to cover a range of types. The times at which the aircraft entered the sector were distributed so that eight to nine aircraft would be present on the scope at 8 minutes and at 16 minutes into the scenario. These were the times at which the scenarios would be stopped and participants would be tested on their situational awareness. It is important to note that the number of aircraft present in the scenario at any given time cannot be completely controlled by the experimenters since the ability of participants to successfully manage the flow of traffic into and out of the airspace affects this variable. This is a characteristic of a free-play simulation.

Training scenarios were developed and varied in complexity. Early in familiarization training, fewer aircraft and fewer conflict situations were included. As training progressed, scenarios increased in complexity to contain the number of aircraft that would be present in the test scenarios. Each test condition used the same scenario. However, the aircraft call signs differed between them. This allowed for a standardized test environment but made it so that participants would be less able to recognize the scenarios as identical. Test scenarios included 14 aircraft, 8 arrivals, 4 departures, and 2 overflights. The majority of aircraft were arrivals since these required more commands to manage successfully.

The version of TRACON used in this experiment allows the user to specify whether to exit the program following a "crash", defined as a separation of aircraft of less than 1/2 mile horizontally or 500 feet vertically. This option was turned off so that the scenario would resume after a crash message, allowing data to be collected while the session was carried to completion. No crashes occurred during the test sessions.

2.2.3 Training.

Participants were first provided with a brief synopsis of the project's background and the overall intent of the work. Prior to receiving hands-on training, participants were provided with an overview to illustrate the basics of TRACON. This included a demonstration by one of the researchers, a former ATCS. Participants were able to observe the way in which aircraft were handled, including how key functions are used to issue commands and the way in which errors (crashes, separation conflicts, handoff errors, missed approaches) are reported. The scenarios were frequently paused so that participants would have the opportunity to ask questions. It was realized that the method by which commands are issued in TRACON II is different from the way in which controllers issue them on the job. Controllers normally communicate with aircraft verbally. This difference was obviously noted, and some of the controllers indicated that it would interfere with their operating abilities. This aspect of controllers' performance is addressed further in the Results and Discussion sections.

Participants were provided with a detailed training manual which included a paper map of the airspace indicating the names and locations of all fixes and airports (see appendix B, page B-8). In addition, a "quick reference card" was provided which described all command entries (see appendix B, page B-12). Six keys (insert, home, page up, delete, end, and page down) and the up, down, left and right arrow keys are used to issue most TRACON commands. Commands were typed onto colored labels and placed over the appropriate keys to facilitate learning and training (see appendix B, pages B-10 and B-11 for illustration).

Instruction was given for each type of aircraft, arrivals, departures, and overflights. The training emphasized efficient ways of managing the different types of aircraft so that minimal keyboard entries would be required. This was done to allow less skilled typists to focus on the job of controlling traffic rather than on keystrokes. Departures and overflights required minimal control instructions unless a conflict situation was pending. Arrivals were the most demanding. To reduce the number of keystrokes used to control arrivals, the necessary control operations were described as a stepwise procedure. Following initial radar contact, one step involved sending the aircraft to a fix location just outside the approach area of the airport, a second involved descending the aircraft to its approach altitude, and the third involved clearing the aircraft for final approach. This technique involved less use of vectoring, and thereby reduced the number of necessary keyboard entries.

Participants were also instructed as to how to issue multiple commands to aircraft and on the use of data tags. These tags included information (usually a destination) which could be typed in and placed under an aircraft's call sign on the scope. Participants were given the option to use them as needed. However, each was encouraged to follow his/her own plan of action if it would better assist control of the traffic. Participants were told that their strategies would be a focus of the research and that they would be asked to indicate the way in which they handled aircraft after each test session.

Each of the hands-on training scenarios was programmed to run for approximately 1/2 hour. Duration of the scenarios varied from individual to individual since their completion depended on the timely and accurate manner in which aircraft were handled. During earlier training sessions, these scenarios typically ran longer since participants were less efficient at managing the traffic. The training and test scenarios shared many of the same types of potential conflict situations, so increased exposure enabled participants to be better prepared to anticipate problems and to practice taking preventive measures.

Participants were monitored throughout training to ensure that they were working effectively and to allow them an opportunity to ask questions. There were two basic stages of training. The first stage involved hands-on experience with TRACON using all of the available computer-generated information, including computer-generated flight strips. The second stage involved working through scenarios while using paper flight strips similar to those used in testing. During these training scenarios, the computer-generated active flight strips were blocked from view. Participants practiced writing on flight strips and also practiced using flight strips that they could only look at and not write on. Participants were provided with additional practice, as needed.

The amount of training time necessary to become proficient with the control commands, airspace configuration, basic control strategies, and separation standards varied with the individual. In general, participants who were computer literate and/or were proficient typists, tended to learn at a faster rate than those who were less familiar with keyboard layout.

Near the end of training, participants were informed that the test sessions would involve a test of their memory for aircraft information when the screen was blocked from view. They were asked to consider how they would be able to manage the traffic if the "radar went out". They were then given a brief sample of what this test environment would be like.

Controllers had restrictive schedules. They were available for a total of 8 hours. Six of these participants had to complete training and testing over the course of 1 day. Training took place during a 3-hour morning time block and testing took place in the afternoon. The other two participants were available for each of two mornings which enabled training to take place 1 day and testing the next.

2.2.4 Test Conditions.

Participants were each tested under two experimental conditions. In one condition, they were required to write notes on the strips while they were working. These strips additionally contained arrows indicating whether aircraft were arrivals (↓), departures (↑), or overflights (↔) as a further organizational tool. In the second condition, participants were not allowed to write notes on the strips. Organization of the strips was also reduced by deleting the arrows.

Participants were provided with flight strips in separate strip holders (see appendix C, page C-1 through C-2 for sample flight strips). This procedure was used to provide controllers with a familiar work setting to minimize any effects of negative transfer to the test environment. Allowing participants to work with separate flight strips enabled analyses to be conducted with respect to different flight strip management techniques used in the test conditions.

2.2.5 Performance Measures.

Participant's were evaluated on situational awareness (SA) and control performance (SCORE) in each condition. SA was tested during 2 intervals in which the on-going scenario was blocked from view. The scenario was "paused" and the display completely covered by a sheet of opaque white paper. This occurred at approximately 8-9 and 16-18 minutes into the scenario. Participants were not informed as to when the SA tests would occur. At these two test points, participants were instructed to report the locations of each of the aircraft currently under their control and to report the last command issued to each. A map of the airspace and a list of the aircraft call signs were provided for them to indicate their responses (see appendix C, pages C-3 through C-5). The map provided minimal reference information and did not include fix names.

SA was evaluated by determining the proportion of correct responses regarding aircraft location and last-issued commands. Actual aircraft locations were determined by uncovering the display screen while still in pause mode and recording each aircraft's placement on the map containing participant responses. Aircraft location reports were scored in the following way: one full point was given if an aircraft was identified and placed correctly on the map. Correct placement meant that it was within 5 miles (1 inch) of its actual location. One-half point was given if the location indicated was within 5 to 7 miles of the actual location, and zero points were given if the location indicated was beyond this limit. One-quarter point was given if a participant indicated that an aircraft was present in a particular location but could not report which aircraft it was.

To indicate aircraft location, participants were required to mark the map with an aircraft identifier, ideally the aircraft call sign. However, in TRACON the call sign does not have the same significance as it does in actual ATC because it is not spoken each time a command is issued. Instead, participants use the keyboard's arrow key to move a cursor to highlight an aircraft. Once highlighted, the commands can be issued to that aircraft via the keyboard. Since the call signs were not as integral a part of the command sequence in TRACON, partial credit (one-half point) was given if the participants were able to mark the appropriate location with a distinguishing identifier (i.e., the aircraft from Anaheim (AHEIM) going to Long Beach at 4000 feet).

Memory for last-issued commands for each identified aircraft was assessed by examining the written reports of participants. Participants were able to refer to the sheet containing the aircraft call signs and recorded the last command issued next to each. In cases in which the call sign could not be paired with an aircraft, participants were told to use other means to identify the aircraft. For example, they could indicate the location of an aircraft (i.e,, the one from SAUGS to Long Beach) and that the last command issued to that aircraft was to descend to 1600 feet.

Performance was assessed by using a modified version of each participant's TRACON-provided score (appendix C, page C-6 for actual TRACON scoring system). TRACON scores are tabulated by adding points for each successfully-completed, significant action, such as landing an aircraft and handing off an aircraft to the next sector. Points are deducted for missed approaches, missed handoffs, separation conflicts, and crashes. Additionally, a smaller number of points is subtracted whenever any command is issued and if substantial delays occur between control actions. Maximum point scores are based on the number of aircraft in the scenario and on the size and type of the aircraft included. Larger aircraft have more point values associated with them than smaller aircraft. Therefore, different scenarios have different maximum possible scores. A maximum of 12780 points was possible in the scenarios used in this experiment.

The TRACON scores alone can be misleading as a reflection of true performance, however, since it is possible for a participant to obtain a relatively high score while taking a very long time to complete the scenario. This would indicate that the aircraft were not handled efficiently. Since this aspect of performance is not adequately reflected in the overall score, a new performance score was derived. This score was obtained by dividing the TRACON score by the time taken to complete the scenario. This "points per minute" score more accurately reflected a participant's efficiency in working traffic and is the performance "SCORE" referred to throughout the remainder of the report.

2.2.6 Procedure.

Prior to the start of the training and test sessions, participants filled out a questionnaire designed to identify factors that may have additionally influenced performance, such as amount of prior experience with TRACON or extent of ATC experience (appendix D, pages D-1 through D-3.

Participants were tested individually so that a record of all of their actions could be accurately maintained by the experimenters. Recordings of every command were kept by category as shown by the example in appendix D, pages D-4 through D-5. The sequence of commands for each aircraft was also noted on these sheets. The sessions were also video-taped for seven of the controllers. Video-tape recordings were made of the computer screen, showing aircraft positions, aircraft movements, commands issued, and feedback messages, and of the participant's flight strip management activities. No full-face video tapes were made in order to protect the identities of the participants. Participants were fully informed, prior to testing, that these events would be recorded.

Experimental sessions were 1-1/4 to 1-1/2 hours long including the intervals during which SA was assessed and the time taken to complete a post-session questionnaire. Both test sessions were conducted on the same day. A break of 10 to 15 minutes separated these sessions to reduce fatigue as much as possible given these circumstances.

Prior to the start of the first experimental session, participants were provided with about 5 minutes of "warm up" time on a short scenario. Participants worked in this short scenario in the same manner that they would in the subsequent test condition, either writing or not writing on the paper strips. The test session started immediately afterwards. Participants were informed that the scenario would be blocked from view at various times throughout the session but were not told when this would occur. They were also told that they would be asked to indicate the location of each aircraft and the last command issued to each, and that during the test interval the paper flight strips would not be available to them.

Participants were given some time to review and rearrange the flight strips before beginning the scenario. Flight strips were placed to the right of the keyboard because all of the controllers tested were right-handed. One of the two researchers (both of whom were also authors of the report) sat to the left and slightly behind each participant to be able to observe each of the commands being issued. The researchers maintained minimal interaction with the participants as they were working. Researchers recorded each command as it was issued on the scoring sheets described above.

At the first stop point, (approximately 8 minutes into each scenario), the display was "paused" by the experimenter and was covered from participants' view. Participants were asked to briefly review their list of active aircraft on their flight strips while the researchers noted on the scoring sheets the last command issued for each aircraft. The participant's flight strips were then removed and they were given the map and the list of aircraft names. Participants had as much time as they felt necessary to indicate all that they could about aircraft locations and commands. They could complete the information in any order they chose. When completed, the display was uncovered, and while still in pause mode, the actual locations of the aircraft were recorded on the airspace map. The list of call signs containing the last-issued commands were collected for subsequent scoring. Participants were then allowed whatever time was necessary to bring themselves up to date before resuming the scenario. At the second stop point, (approximately 16 minutes into the scenario), the display was paused again and this procedure was repeated. Following this second test interval, the scenario was run to completion.

The scoring information provided by TRACON was recorded immediately after the scenario ended (see appendix D, page D-6). Participants also indicated their perceived level of workload for the session using the 12-point scale at the bottom of this sheet, with 1 indicating the lowest and 12 the highest possible workload level. Participants also completed a post-session questionnaire following each of the experimental sessions in order to provide additional information as to what may have affected their performance (see appendix D, pages D-7 through D-9). In addition, the experimenters discussed performance with participants to elicit more information about their strategies.

2.2.7 Design.

A 2 x 2 mixed design was using in which TEST CONDITION (WRITING vs. NO WRITING) served as the within-subjects factor and TEST ORDER (WRITING condition first or second) served as the between-subjects factor (see table 2-1). The order for testing participants was counterbalanced to reduce the confounding effect of practice on the conditions under investigation. SA and performance (SCORE) served as dependent variables. In all analyses, the two dependent variables were analyzed separately in keeping with the distinction proposed by Endsley (1989). She argued that situational awareness should be considered separately from decision making and performance because it is possible, for example, to achieve high situational awareness but not have other skills necessary to properly formulate decision strategies or carry out appropriate actions.

TABLE 2-1. EXPERIMENTAL DESIGN

	WRITING	NO WRITING
ORDER = 1	2nd	1st
ORDER = 2	1st	2nd

Note. Participants worked under both the WRITING and the NO WRITING conditions in the order indicated.

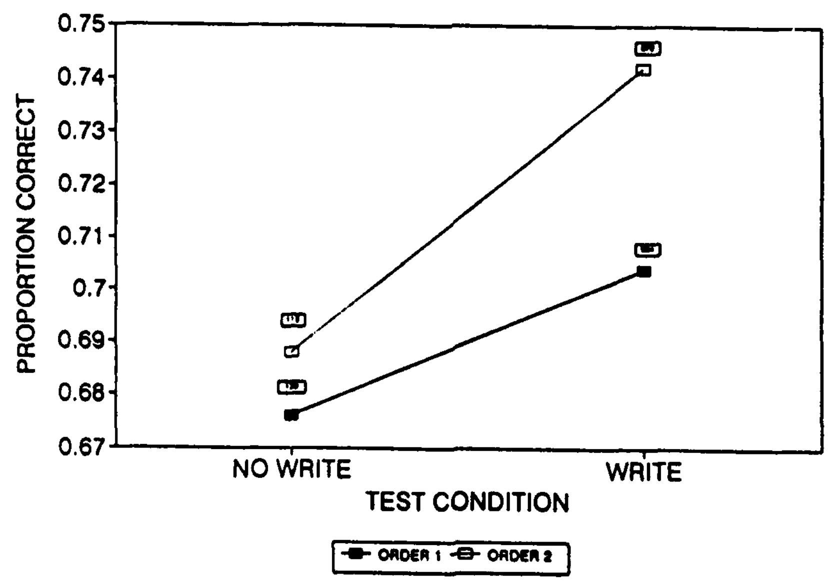
These data were analyzed using a statistical package for the pc, the Statistical Package for Social Sciences (SPSS). Analysis of variance (ANOVA), a statistical procedure used to determine whether the differences between two or more means are significant, was used to evaluate differences in performance scores and SA scores as a function of CONDITION, ORDER, and the CONDITION x ORDER interaction. A multiple regression analysis was conducted on the preliminary questionnaire variables and performance scores. Similarly, a multiple regression analysis was conducted on the preliminary questionnaire variables and SA scores. Partial correlations were obtained from these analyses to determine the relationship between each independent variable (i.e., level of stress) and each dependent variable (i.e., performance). This procedure partitions out the combined effects of correlated independent variables (i.e., stress and fatigue) on the dependent variable, so that only the relationship of individual variables is determined.

Other ANOVA's were conducted to evaluate differences between test conditions on post-session questionnaire variables, (e.g., level of perceived workload, level of stress). The relationship between various strategies and performance was also investigated. The proportions of several command-types (e.g., altitude changes, speed changes) were analyzed as a function of test condition to determine whether certain commands were used more in one condition or another.

An analysis of the video-tapes was also conducted to determine whether flight strip management differed between test conditions. The number of non-writing actions (arranging strip placement or cocking strips left/right) was determined for each test condition and compared.

3. RESULTS.

Controllers' SA did not differ significantly between test conditions, $F(1,6)=1.05$, $P>.05$ (see figure 3-1). In addition, neither the effect of ORDER, $F(1,6)=.18$, $p>.05$, nor the interaction of ORDER x CONDITION, $F(1,6)=.12$, $p>.05$, were significant. SCORE also did not differ significantly as a function of CONDITION, ORDER, or their interaction, $p>.05$,. An analysis of covariance (ANCOVA) was also conducted on these data with the ORDER variable as the covariate. No significant differences were found ($p>.05$).



Note. Standard deviations above each data point.

FIGURE 3-1. MEAN SA SCORE AS A FUNCTION OF CONDITION AND TEST ORDER.

In addition to the performance measures described, post-session questionnaire responses were examined to determine whether participants reported any differences between operating under the WRITING condition and the NO WRITING condition. Each participant provided an assessment of his/her performance (ASSESS), and gave ratings of perceived levels of workload (WORKLOAD), busyness (BUSY), thinking and concentration (THINK), stress (STRESS), and fatigue (FATIGUE). Participants also reported how helpful they felt the flight strips were in each condition. They rated how much the strips assisted their control performance (CONTROL) and how much the strips assisted their SA (MEMORY). Ratings were provided using a ten-point scale in which one was the lowest and ten was the highest response level. Workload, however, was reported using a 12-point scale.

Analyses of the post-session questionnaire variables indicated that the controller's self-assessment ratings were found to differ significantly between test conditions, $F(1,6)=10.71$, $p<.05$. They reported that their performance was poorer under the WRITING condition. The effect of ORDER was not significant, $F(1,6)=.08$, $p>.05$, however, the ORDER x CONDITION interaction was significant, $F(1,6)=10.71$, $p<.05$. Planned contrasts indicated that controllers who worked under the NO WRITING condition first, reported a greater perceived difference in their performance between the two conditions, $F(1,6)=6.97$, $p<.05$.

For the FATIGUE variable, neither main effect was significant ($p>.05$), however, the ORDER x CONDITION interaction was significant, $F(1,6)=11.71$, $p<.05$. Contrasts indicated that controllers who worked under the WRITING condition first, reported being more tired under the second test condition, $F(1,6)=1.97$, $p<.05$.

None of the other main effects or interactions were found significant for the post-session questionnaire variables, $p>.05$.

For the preliminary questionnaire variables, partial correlations indicated that level of video-game experience was positively correlated with SA under the NO WRITING condition (+.84, $p<.05$), see table 3-1. This relationship will be discussed in further detail in a subsequent section. None of the preliminary questionnaire variables correlated significantly with SCORE in the NO WRITING condition and none of these variables were found to correlate with SA or SCORE in the WRITING condition.

3.1 ADDITIONAL ANALYSES.

The data were analyzed further in order to learn more about the control strategies and flight strip management techniques used to work through the test conditions presented in the current experiment. Quantitative measures of several of these strategies and techniques are described below. Although many of the differences reported were not found to be significant, they suggest some potential trends and are, therefore, worthy of report.

TABLE 3-1. CORRELATION MATRIX FOR PRELIMINARY QUESTIONNAIRE VARIABLES AND SA IN THE NO WRITING CONDITION.

	SA	YRS	CO	VID	VIS	STR	MO
SA	1.00	.197	.484	.842	-.008	-.091	-.231
YRS	.197	1.00	-.076	-.075	.243	.460	-.244
CO	.484	-.076	1.00	.755	.332	-.206	-.137
VID	.842	-.075	.755	1.00	-.158	-.141	.052
VIS	-.008	.243	.332	-.158	1.00	.201	-.373
STR	-.091	.460	-.206	-.141	.201	1.00	.586
MO	-.231	-.244	-.137	.052	-.373	.586	1.00

Note: SA=situational awareness, YRS=years of ATC experience, CO=computer experience, VID=video game experience, VIS=vision, STR=stress, MO=motivation.

Further analyses revealed that there was a significant negative correlation between the number of commands issued in the NO WRITING condition and SA, (-.83, $p<.01$, df=7). SA decreased as the number of transmissions made increased. This correlation did not reach significance for the WRITING condition, (-.73, $p>.05$, df=7). This result suggests that it was more difficult for participants to maintain critical information in memory the more commands they issued, particularly when they were unable to record this information on flight strips. Controllers in this experiment wrote an average of only 47 percent of their actions on their flight strips. They wrote altitude changes almost exclusively, as they are required on the job. Altitude changes were recorded significantly more often than turn/heading changes or speed changes, $F(2,6)=15.30$, $p<.001$ (see table 3-2).

TABLE 3-2. PROPORTION OF COMMANDS WRITTEN BY TYPE.

ALTITUDE	TURN	SPEED
.886 (.312)	**.041** (.067)	**.313** (.513)

These proportions were obtained by comparing the number of commands written by the number of commands issued in each category. The high proportion of altitude changes recorded also reflects the fact that participants wrote proposed altitude changes on their strips that they sometimes did not carry out.

The data were also examined to determine whether different types of commands were issued in the two test conditions. It might be expected that proportionately fewer altitude changes would be made under the condition in which notes could not be kept on strips since participants would not have their usual record of those changes and would presumably be less familiar with ways to remember them. The use of flight strips for recording altitude changes over other status changes is meaningful. Altitude information can not be obtained from the display screen as directly as turn/heading changes, for example. Those changes can be observed by looking at the direction of the aircraft's icon on the scope. The only information provided on the scope about an altitude change is the up/down (ascending/descending) arrow notation located next to the aircraft's current altitude, all of which is presented below the call sign. The controller cannot determine the exact altitude to which he/she has sent the aircraft unless the information is remembered or available on the flight strip. Investigating whether control strategies differed between test conditions seemed especially worthwhile since one controller described that, in the event of radar failure when only flight strips are available, altitude separation is used almost exclusively.

The proportion of command-types issued under each test condition was examined. The difference between the overall proportion of command types issued under each test condition did not reach significance, $F(1,6)=3.92$, $p>.05$. The TYPE x CONDITION interaction was also not significant ($p>.05$), indicating that the proportion of these different command types did not differ when participants had the opportunity to write on strips than when they did not. Participants, therefore, did not issue significantly fewer altitude changes, or significantly more turn/heading changes, when they were unable to write on strips.

Another attempt was made to investigate differences between the two test conditions by comparing only memory for the last command, if that command was an altitude change. Using the reasoning above, it should presumably be more difficult for controllers to remember altitude changes if they were unable to write on strips. Altitudes were the last commands issued in only two to eight occasions in each test condition. Since the last command issued at each test interval varied from one individual to another, proportions were not based on an equal number of observations across either individuals or test conditions. Using the information that was available, it was found that the mean proportion of altitudes recalled in the NO WRITING condition was .557 (SD=.334) and .729 (SD=.215) in the WRITING condition. This difference, however, did not reach significance, $F(1,7)=1.56$, $p>.05$.

Other aspects of the participants' flight strip management techniques were investigated. Since participants used flight strips that were placed in separate holders and in strip bays, they were able to alter strip placement by rearranging the order of the strips, offsetting ("cocking") them left or right, or by grouping them. One possible reason why no differences in SA were found between the test conditions may have been due to the use of different strip management techniques in each condition. These different techniques may have been used as memory joggers when writing on strips was not allowed. For example, a strip may have been offset to indicate that a further action was needed, or several strips may have been grouped together to indicate that all were going to the same destination. Participants may have been using more of these techniques in the NO WRITING condition to compensate for their inability to keep notes.

To determine this, the video tapes of the strip management activities were analyzed. All non-writing activities were sorted into categories and counted. Non-writing activities included cocking the strips, separating them into groups, rearranging strip placement, bringing strips from the pending to the active bay, removing strips from the active bay, and sliding strips in the active bay into better view. A proportion of organizational (grouping) or "cue-related" (offsetting) activities was determined from the total. This proportion did not include actions which brought strips into and out of the active bay (without organizing or offsetting them), those which involved touching but not moving the strip, or those in which all the active strips were moved to a more visible location (i.e., slid further down the bay and into view), leaving their relative placement unchanged.

The mean proportion of flight strip management activities was 23.57 (SD=5.6) in the NO WRITING condition and 20.29 (SD=6.6) in the WRITING condition. The small difference observed in the means, however, did not reach significance, $t(6)=+1.70$, $p>.05$. From the proportion of activities included, it could not be determined that more "organizational" or "cue-related" activities, as categorized here, were used in the NO WRITING condition.

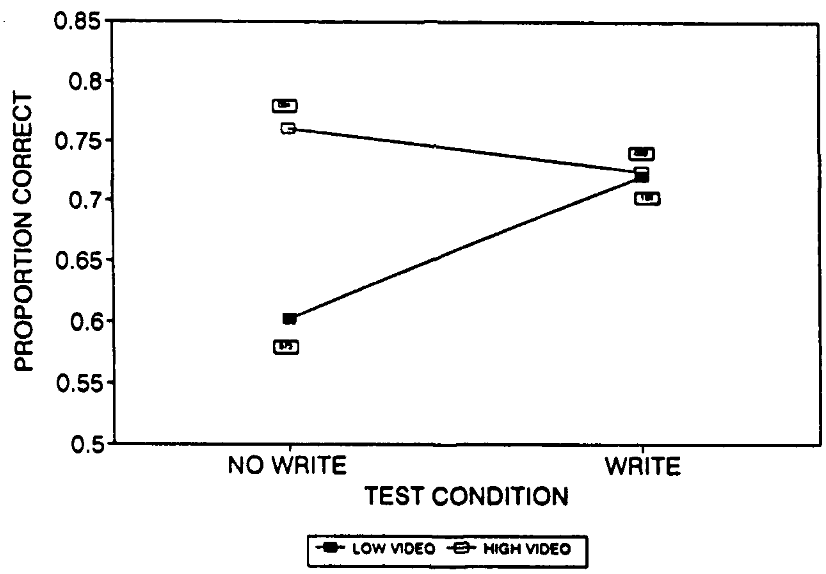
Finally, one very compelling result of this experiment was observed. Several controllers had commented on their inability to remember aircraft call signs in the current experiment, something which they did not feel was a problem for them on the job. It is assumed that controllers do remember call signs better on the job, but such information was not available in the current experiment. Controllers in this experiment remembered an average of only 82 percent of the call signs. One controller remembered just 20 percent. Memory for call signs was also examined between test conditions, under the assumption that it may have been somewhat easier for controllers to remember call signs when they had some type of further interaction with the aircraft information. Call signs were recalled 79 percent of the time under the NO WRITING condition and 84 percent of the time under the WRITING condition, a difference that did not reach significance, $p>.05$.

The observation that controllers did not remember aircraft call signs as well as they report they normally do, is important. Controllers indicated that this was due to their having to issue commands via the keyboard, rather than verbally. The fact that controllers were not saying the aircraft call signs out loud prior to issuing a command may have made the call signs less salient in memory. The articulatory loop notion supports this view. It proposes that articulation of information is valuable in assisting recall. When articulation of material is prevented or when articulation of conflicting material is required, memory deteriorates (Baddeley, Thompson, and Buchanan, 1975). On a broader scale, this also reflects the importance of active encoding.

Physically (here, verbally) interacting with material enhances its ability to be remembered. Without such interaction, memory has been observed to be degraded. The observation that call signs were not remembered with high accuracy in this experiment should be taken into consideration and investigated further before any changes to reduce or eliminate verbal communication are made to the ATC system.

3.2 OTHER FACTORS AFFECTING PERFORMANCE.

Information from the preliminary questionnaire indicated that participants' SA in the NO WRITING condition was correlated with level of reported video-game experience. SA was higher for participants who reported a higher level of video-game experience. To further analyze this data, the participants were divided according to the level of video-game experience reported. Those reporting less than the average value (4) were designated the "LOW VIDEO" group, and those reporting a value higher than 4 were designated the "HIGH VIDEO" group. SA for these groups is presented in figure 3-2.



Note. Standard deviations above data points.

FIGURE 3-2. SA SCORE AS A FUNCTION OF VIDEO-GAME EXPERIENCE

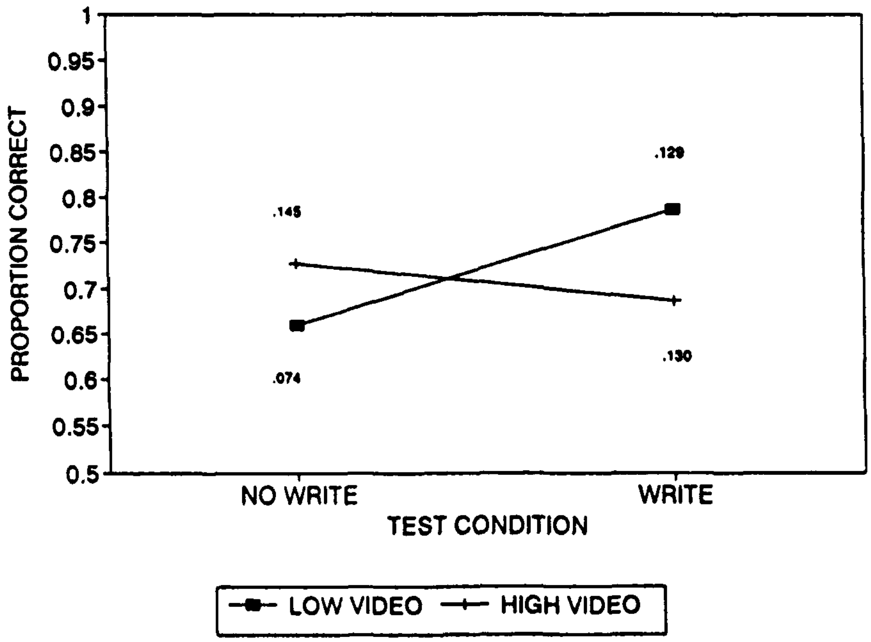
An ANOVA indicated that neither the CONDITION nor the GROUP main effects were significant ($p > .05$), however, the GROUP x CONDITION interaction was significant,

$F(1,6)=9.32$, $p<.05$. Planned contrasts revealed that the HIGH and LOW VIDEO groups performed equally well under the WRITING condition, $F(1,6)=.007$, $p>.05$, but the LOW VIDEO group performed more poorly under the NO WRITING condition, $F(1,6)=8.62$, $p<.05$. The LOW VIDEO group's SA improved between the NO WRITING and WRITING conditions, $F(1,6)=10.91$, $p<.05$, but the HIGH VIDEO group's SA did not differ between test conditions, $F(1,6)=1.07$, $p>.05$.

This result indicates that those participants who were less familiar with video games were less able to maintain SA when they were unable to use a written memory backup. It is possible that so much of their concentration was focused on manually issuing commands and receiving feedback from the screen, that they were unable to devote enough attention to the memory component of the task required. Having less experience in these areas may require that too much attention be devoted to those tasks and may take away from the ability to keep other aspects of the situation in memory.

SA had been measured by combining the proportion of correct responses regarding aircraft locations and the proportion of correct responses regarding last-issued commands into a single score. The question remained as to whether differences between these groups of controllers were due to differences between one of these measures more than the other. Memory for locations and memory for last-issued commands were therefore analyzed separately.

Mean proportions of correct responses for aircraft locations are presented in figure 3-3 for each controller group and each test condition.

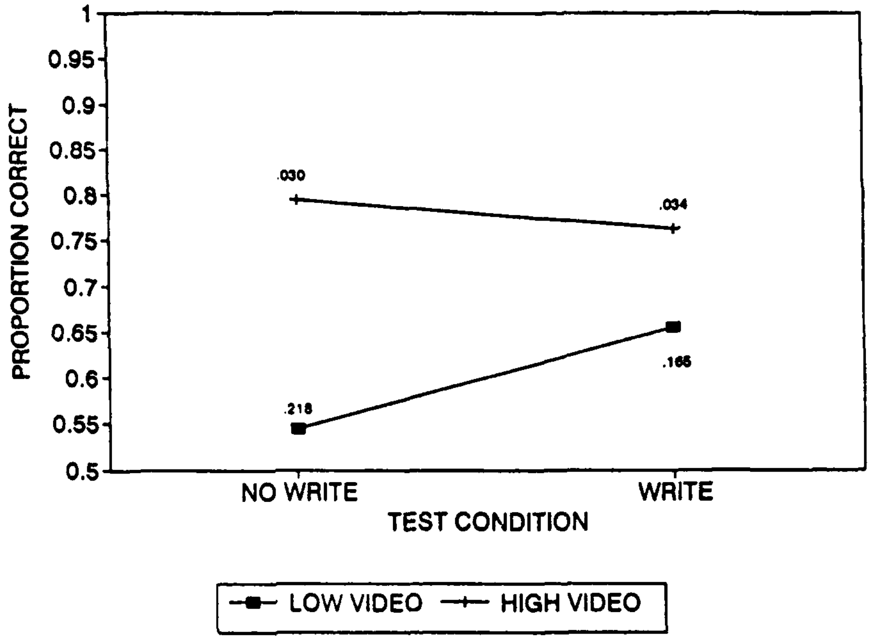


Note. Standard deviations adjacent to data points.

FIGURE 3-3. MEAN PROPORTION CORRECT: LOCATIONS OF AIRCRAFT

Groups did not differ significantly with respect to the proportion of correctly located aircraft, $F(1,6)=.06$, $p>.05$. Neither were there significant differences found as a function of CONDITION, $F(1,6)=.68$, $p>.05$, or CONDITION x GROUP, $F(1,6)=2.49$, $p>.05$. Controllers with different levels of video-game experience did not differ on their ability to correctly indicate locations of aircraft when the display was not visible.

Each group's mean proportion of correct responses regarding last-issued commands under each condition is presented in figure 3-4. Groups did differ in their memory for last commands issued, $F(1,6)=6.28$, $p<.05$. The LOW VIDEO group's memory was poorer than the HIGH VIDEO group's. Contrasts indicated that differences between these groups neared, but did not reach significance under the NO WRITING condition, $F(1,6)=5.16$, $p>.05$. Differences as a function of CONDITION were not significant, $F(1,6)=.33$, $p>.05$, nor were differences as a function of CONDITION x GROUP, $F(1,6)=1.13$, $p>.05$.

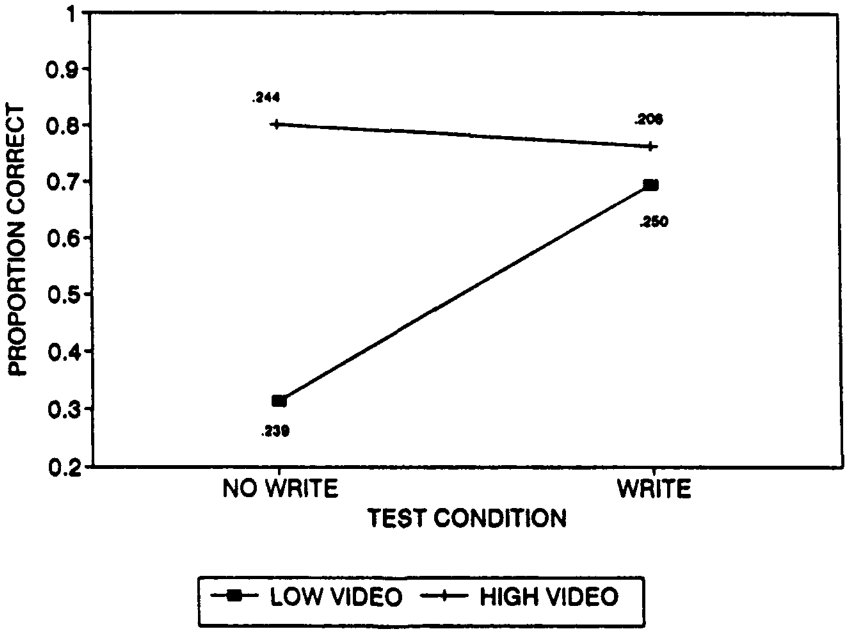


Note. Standard deviations adjacent to data points

FIGURE 3-4. MEAN PROPORTION CORRECT: LAST COMMAND ISSUED

Memory for last-issued commands was investigated further for these groups to determine whether there were differences in the types of information that each group was able to recall. The analysis focused on determining whether controllers in the LOW VIDEO group were less able to recall altitudes than those in the HIGH VIDEO group. This analysis was conducted because controllers typically use flight strips to record changes in altitude, a finding that was also observed in this experiment. Since controllers in the LOW VIDEO group appeared more dependent on strips, they were expected to remember fewer altitude changes when note-writing on strips was not allowed.

The proportion of correctly-remembered altitude changes was measured, rather than the actual number of altitude changes, since the actual number varied for each individual and each test condition. The last command issued was determined solely by the actions of the controller and so the experimenters did not have control over the types of commands that would be issued last to each aircraft prior to pausing the scenario. Mean proportions of remembered altitude changes are presented in figure 3-5.



Note. Standard deviations adjacent to data points.

FIGURE 3-5. MEAN PROPORTION CORRECT: LAST ALTITUDE CHANGE ISSUED

Groups differed in terms of the proportion of altitude changes that they correctly remembered. The LOW VIDEO group remembered a significantly lower proportion of altitude changes than the HIGH VIDEO group, $F(1,6)=5.91$, $p<.05$. These controllers differed in terms of their ability to recall altitudes in the NO WRITING condition as indicated by contrasts. Controllers in the LOW VIDEO group remembered a significantly lower proportion of altitude changes than did those in the HIGH VIDEO group under the NO WRITING test condition, $F(1,6)=8.23$,$p<.05$. Differences as a function of CONDITION were not significant overall, $F(1,6)=2.02$, $p>.05$, nor were differences as a function of GROUP x CONDITION, $F(1,6)=3.07$, $p>.05$. For the LOW VIDEO group, the difference between the proportion of altitude changes remembered in each test condition neared, but did not reach significance, $F(1,6)=5.04$, $p>.05$, as indicated by contrasts. Controllers in this group were somewhat less accurate in remembering altitude changes in the NO WRITING condition than they were when they were able to keep notes on strips. No suggestion of such a trend was found for controllers in the HIGH VIDEO group.

4. DISCUSSION.

The results indicated that there were no differences in situational awareness or control performance between test conditions when level of video-game experience was not considered. This result suggests that writing on flight strips is not as critical to ATC performance or for keeping the "picture" as has been previously suggested (Hopkin, 1991). However, in this experiment, terminal controllers were studied exclusively. Different results may have been found for en route controllers.

While note-writing was not found to improve controllers' situational awareness, it is still possible that other flight strip management activities may have been valuable. A follow-up experiment, comparing situational awareness under conditions in which participants can and cannot rearrange strip placement, for example, would be needed to determine the importance of such activities.

There are several alternative explanations for the results. One possible explanation is that the scenarios used in this experiment may not have required the use of flight strips in order for controllers to maintain situational awareness. For example, controllers may have been able to identify patterns in the traffic which they used to guide their organization of aircraft locations and their memory for the action steps taken with them.

Another possible explanation is that controllers thought both test conditions were too easy to have found flight strip management activities like note-writing beneficial. This seems unlikely, however, given that controllers' workload reports were moderately high, averaging 7.3 on a 12-point scale, suggesting that they felt at least somewhat challenged by the scenarios provided.

Another explanation may lie in the method by which situational awareness was measured. Participants in this experiment knew in advance that the scenarios would be stopped at various times and that they would be specifically asked about the last commands issued and the locations of the aircraft. Pausing the scenario and probing directly for specific information could have caused controllers to focus on only those components of the task while ignoring others and may have biased them to use different memory techniques than they normally would on the job. For example, controllers may have rehearsed some of this information in order to remember it for these test purposes, but may not typically rehearse such information when working with real traffic. Such concerns about intrusive methods of situational awareness assessment have been raised previously (Sarter and Woods, 1991).

Some differences in controller situational awareness may have occurred in the present experiment, but the measures used here may have been too insensitive to detect them. Sample size was small and power may not have been sufficient to detect significant differences. Larger sample sizes along with less intrusive measures of situational awareness may be valuable in determining whether controllers' situational awareness differs under such conditions.

Another explanation, and one supported by the work conducted here, is that certain individuals may benefit more from flight strip management activities than others, given the nature of the task demands. In this experiment, controllers who reported lower levels of video-game experience benefitted from keeping notes on flight strips. Their situational awareness improved under this condition. Controllers who reported higher levels of video-game experience maintained situational awareness equally between both test conditions. Additionally, further analyses indicated that different aspects of situational awareness were affected. Groups did not differ in terms of their memory for visual information. Memory for aircraft locations did not differ between the groups or between the test conditions. However, groups did differ with respect to memory for other, non-visual components of the task. Memory for commands, specifically memory for altitude changes, was lower for those reporting a lower level of experience. Differences between groups were most prominent for the NO WRITING condition. Not being able to write on flight strips was apparently more detrimental for controllers with lower video-game experience than for those reporting a higher level of experience.

These results suggest that individuals who are not experienced interacting with equipment in which commands are issued manually and feedback is received visually may have a more difficult time maintaining situational awareness without a memory backup. Note-writing may be helpful to these individuals because it may provide a way for them to keep track of critical information when much of their attention needs to be devoted to the technique involved in interacting with the equipment. Such a result has implications for the performance of certain individuals in more automated systems that rely on this form of interaction.

Finally, one other compelling finding of the current experiment was that controllers indicated being less able to remember aircraft call signs under these conditions, in which commands were issued via the keyboard, than they are on the job, in which commands are issued verbally. Future work will need to identify whether this phenomenon holds after participants have had more experience with the equipment. Nevertheless, this finding also has ramifications for any system that will involve the use of computer-entered commands. The potential exists for controllers to have difficulty identifying aircraft appropriately.

5. RECOMMENDATIONS.

The results obtained in this experiment suggest that certain individuals may benefit from using flight strip management techniques as a memory back-up when keyboard entries are required.

Future work is needed to determine how these individuals are affected by continued practice with such systems and whether the reliance on such memory aids declines with increasing experience.

The finding that different individuals benefitted from different memory strategies under various task conditions suggests that research into effective memory aids may need to be pursued from an individualized, controller-centered perspective. Programs that train controllers to identify their own memory limitations and requirements and which provide controllers with a variety of memory-aiding strategies that can be implemented on a situation-specific basis, may prove the most useful approach. Controllers, for example, can be trained to become more aware of factors that influence memory and performance (e.g., stress, fatigue). They can be instructed on how to enhance their self-awareness of these factors and on how to determine the extent to which they are affected by them.

Controllers can also be specifically instructed on a variety of general memory-enhancing principles, such as task organization and standardization, and trained on how to develop and implement these skills as needed. Examples can be provided and controllers can practice implementing these skills using realistic scenarios presented on high-fidelity simulators. Emphasizing the development of individualized memory strategies is useful in that the basic skills acquired can be applied to a variety of work conditions. They would therefore be useful to controllers over the long-term, in both current and future air traffic control systems. Such training programs need to be developed and evaluated since they provide a potentially promising way to reduce cognitive load and improve ATC safety and efficiency.

6. IMPLICATIONS.

There are several important implications that emerge from this research. They are:

a. Controllers' performance with certain ATC systems may depend upon the amount of prior experience they have had with complex systems like video games which require rapid decision making and skilled eye-hand coordination. Controllers with more extensive experience using such interactive devices may be more readily able to perform the kinds of tasks required here without having to rely on memory aids. In this experiment, controllers with higher video-game experience performed equally well under both test conditions.

b. Memory lapses and effective memory-aiding techniques may differ between different subgroups of controllers depending on their knowledge of and skill level with various systems. In this experiment, only those controllers reporting lower levels of video-game experience improved their situational awareness (SA) significantly when they were allowed to keep notes on flight strips.

c. Results of research conducted with low-fidelity systems can not be directly translated to the present ATC environment. In this experiment, the simulator used required keyboard rather than verbal communication to issue commands to aircraft. This condition made the control of aircraft very different from that used in the real-world ATC system. One result was that controllers reported being less able to remember aircraft call signs in this experiment than they report they are on the job. Although controllers were willing and able to use the low-fidelity system, testing must be conducted with high-fidelity simulators and eventually in the operational environment in order for the results of the work to be directly pertinent to current job conditions.

REFERENCES

Baddeley, A.D. (1986), Working memory. Oxford: Clarendon Press.

Baddeley, A.D., Thompson, N., and Buchanan, M. (1975), Word length and the structures of short-term memory. Journal of Verbal Learning and Verbal Behavior, 14, 575-589.

Bower, G.H., Clark, M.C., Lesgold, A.M., and Winzenz, D. (1969), Hierarchical retrieval schemes in recall of categorized work lists, Journal of Verbal Learning and Verbal Behavior, 8, 323-343.

Endsley, M.R. (1989), A methodology for the objective measurement of pilot situation awareness. Proceedings of the AGARD Symposium on Situational Awareness in Aerospace Operations. Neuilly Sur Seine, France.

FAA (1987), Profile of Operational Errors in the National Airspace System, Calendar Year 1986. Washington, D.C.

FAA (1988), Profile of Operational Errors in the National Airspace System, Calendar Year 1987. Washington, D.C.

FAA (1989), Air traffic control, (DOT/FAA Handbook 7110.65F), Washington D.C.: U.S. Government Printing Office.

FAA (1992), Administrator's Fact Book (AMS-400), Washington, D.C.: U.S. Government Printing Office.

Finkleman, J.M. and Kirchner, C. (1980), An information processing interpretation of air traffic control stress, Human Factors, 22, 561-567.

Garland, D.J., Stein, E.S., Blanchard, J.W., and Wise, J.A. (1992), Situational awareness in the future air traffic control environment. Proceedings of the 37th Air Traffic Control Association Conference, Atlantic City, N.J.

Gromelski, S., Davidson, L., and Stein, E. (1992), Controller Memory Enhancement: Field Facility Concepts and Techniques, (DOT/FAA/CT-TN92/7), Atlantic City, N.J.: DOT/FAA Technical Center.

Hopkin, V.D. (1988), Human factors aspects of the AERA 2 program, Farnborough, Hampshire, England: Royal Air force Institute of Aviation Medicine.

Hopkin, V.D. (1991), Automated flight strip usage: Lessons from the functions of paper strips, Challenges in Aviation Human Factors: The National Plan, American Institute of Aeronautics and Astronautics.

Hopkin, V.D. (1991a), The impact of automation on air traffic control systems, In J.A. Wise, V.D. Hopkin, and M.L. Smith (eds.), Automation and systems issues in air traffic control. (pp. 3-19), Berlin: Springer-Verlag.

Hopkin, V.D. (1991b), Closing remarks, In J.A. Wise, V.D. Hopkin, and M.L. Smith (eds.), Automation and systems issues in air traffic control, (pp. 553-559), Berlin: Springer-Verlag.

Jackson, A. (1989), The functionality of flight strips, Report to the U.K. Civil Aviation Authority: Royal Signals and Radar Establishment.

Kinney, G.C., Spahn, M.J., and Amato, R.A. (1977), The Human Element in Air Traffic Control: Observations and Analyses of the Performance of Controllers and Supervisors in Providing Separation Services, Report No. MTR-7655. McLean, Va., The MITRE Corporation.

Kirchner, J.H. and Laurig, W. (1971), The human operator in air traffic control, Ergonomics, 14, 549-556.

Klapp, S.T., Marshburn, E.A., and Lester, P.T. (1983), Short-term memory does not involve the "working memory" of information processing: The demise of a common assumption. Journal of Experimental Psychology: General, 112, 240-264.

Koriat, A., Ben-Zur, H., and Nussbaum, A. (1990), Encoding information for future action: Memory for to-be-performed tasks versus memory for to-be-recalled tasks, Memory and Cognition, 18, 568-578.

Means, B., Mumaw, R., Roth, C., Schlager, M., McWilliam, E., Gagne, V. R., Rosenthal, D., and Heon, S. (1988), ATC training analysis study: Design of the next generation ATC training system. Washington, D.C.: Federal Aviation Administration.

Miller, G. (1956), The magic number seven plus or minus two: Some limits on our capacity for processing information. Psychological Review, 63, 81-97.

Moray, N. (1986), Monitoring behavior and supervisory control. In J. Rasmussen and W. B. Rouse (Eds.) Handbook of perception and human performance: Volume II, cognitive processes and performance (pp. 40-1- 40-51). New York: Wiley.

Norman, D. (1992), Turn Signals are the Facial Expressions of Automobiles. Reading, MA: Addison-Wesley.

Operational Error Analysis Work Group (1987), Actions to implement recommendations of April 17, 1987, Unpublished manuscript, Federal Aviation Administration, Washington D.C.

Rasmussen, J. (1987), Cognitive control and human error mechanisms. In J. Rasmussen, K. Duncan, and J. Leplat (Eds.), New Technology and Human Error,(pp. 53-60). New York: John Wiley and Sons.

Rasmussen, J. and Lind, M. (1982), A Model of Human Decision-Making in Complex Systems and Its Use for Design of System Control Strategies. (Report No. RISO-M-2349). Denmark: RISO National Laboratory.

Sarter, N.B. and Woods, D.D. (1991), Situation awareness: A critical but ill-defined phenomenon. The International Journal of Aviation Psychology, 1, 45-57.

Senders, J.W. and Moray, N.P. (1991), Human Error: Cause, Prediction, and Reduction. Hillsdale, N.J.: Lawrence Erlbaum Associates.

Sperandio, J.M. (1971), Variations of operator's strategies in regulating the effects of workload, Ergonomics, 14, 571-577.

Spettel, C.M. and Liebert, R.M. (1986), Training for safety in automated person-machine systems, American Psychologist, 41, 545-550.

Stein, E.S. (1991), Air traffic controller memory-a field survey (DOT/FAA/CT-TN90/60), Atlantic City, N.J.: DOT/FAA Technical Center.

Stein, E.S. and Bailey, J. (1989), The controller memory handbook, (DOT/FAA/CT-TN89/58), Atlantic City, N.J.: DOT/FAA Technical Center.

Thomas, D.D. (1985), ATC in transition, 1956-1963, Journal of ATC, 30-38.

Tulving, E. (1962), Subjective organization in free recall of "unrelated" words. Psychological Review, 69, 344-354.

Vingelis, P.J., Schaeffer, E., Stringer, P., Gromelski, S., and Ahmed, B., (1990), Air Traffic Controller Memory Enhancement-Literature Review and Proposed Memory Aids. (DOT/FAA/CT-TN90/38), Atlantic City, N.J.: DOT/FAA Technical Center.

Vortac, O.U. (1991), Cognitive factors in the use of flight progress strips: Implications for automation. Unpublished technical report, Norman, OK: University of Oklahoma.

Vortac, O.U., Edwards, M.B., Jones, J.P. Manning, C.A., and Rotter, A.J. (1992), En-route Air Traffic Controllers Use of Flight Progress Strips: A Graph Theoretical Analysis (DOT/FAA AM-92/31). Oklahoma City: FAA Civil Aeromedical Institute.

Warm, J.S., and Dember, W.M. (1986), Awake at the switch, Psychology Today, 20, 46-53.

Wesson, R.B. and Young, D. (1990) TRACON II: Multi-player air traffic control simulator. [computer software system]. Austin, TX: Wesson International.

Zimmer, H.D. (1986), The memory trace of semantic or motor processing, In F. Klix and H. Hagendorf (eds.), Human Memory and Cognitive Capabilities: Mechanisms and Performances. Part A.

Zingale, C., Gromelski, S., and Stein, E.S. (1992), Preliminary Studies of Planning and Flight Strip Use as Air Traffic Controller Memory Aids. (DOT/FAA/CT-TN92/22) Atlantic City, N.J.: DOT/FAA Technical Center.

APPENDIX A

PILOT STUDIES WITH NON-CONTROLLERS

Pilot Work on Effects of Flight Strip Use on Situational Awareness: Non-Controller Participants

Two groups of non-controllers participated in pilot work to obtain preliminary information as the usefulness of flight strips to situational awareness (SA). Practice, training, and testing were conducted using methods similar to those described for controllers. The results for each of these groups and the specific differences in methodology used to conduct this work are indicated below.

The first group of non-controllers tested consisted of aviation students from Mercer County Community College (MCCC) and were recruited from the school's flight club. This was the same pool from which participants had been selected for a prior experiment (Zingale, Gromelski, and Stein, 1992). Priority was given to those students who had participated in the earlier experiment in order to take advantage of their experience with TRACON. Data from eight participants were included in the final analyses, three of whom had participated previously. All students who completed the experiment received 4 hours of flight time as an incentive for participation in the study.

The ages of the participants in this group ranged from 19 to 25 (mean=21.25, SD=2.55). They had completed from zero to two semesters in the aviation program (mean=.75, SD=1.04) and from zero to six ground courses (mean=2.13, SD=2.36) prior to their participation in this experiment. Their flight experience varied considerably, ranging from 23 to 165 hours of actual flight time (mean=73.13, SD=47.50). Three of these participants also reported having some additional aviation experience prior to attending MCCC.

Students gave themselves fairly low ratings in terms of their computer experience (mean=3.87, SD=1.89) and somewhat higher ratings in terms of their video-game experience (mean=6.12, SD=2.30). Reported stress levels varied (mean=4.50, SD=2.45). Level of reported vision (mean=9.00, SD=1.77) and health (mean=9.63, SD=.52) were quite high as was motivational level (mean=2.00, SD=1.77). Participants also indicated that they freely volunteered to participate in the study (mean=9.50, SD=.76).

The second group of non-controller participants consisted of employees of the Federal Aviation Administration (FAA) Technical Center. This group had worked on air traffic control (ATC)-related projects, but were not controllers by profession and had no formal training in air traffic control. These participants were recruited through an office memo which briefly described the study and requested that anyone interested in volunteering attend an introductory meeting. A total of seven participants from this group were tested. This group consisted mostly of people with advanced degrees and/or considerable work experience in technical areas, such as computer programming.

Two of the participants from this group had prior experience with TRACON or with a similar computer game. Overall, they rated themselves quite high in terms of their computer experience (mean=8.00, SD=1.73), and fairly low in terms of their video-game experience (mean=4.00, SD=2.08). Level of reported vision was fairly low (mean=7.00, SD=2.08). Stress levels varied (mean=4.71, SD=2.06). These participants reported themselves in very good health (mean=9.57, SD=.53) and indicated that they freely volunteered to participate in the study (mean=9.57, SD=.53). Motivational level was generally high but variable (mean=2.71, SD=3.30).

These groups were each tested at their own sites, using the equipment available at each location. The aviation students were tested first, in one of the computer laboratories on the MCCC campus. At this location, computers with slower processing capabilities (286) were available. Technical Center employees were tested at the FAA Technical Center's Human Factors Laboratory. Here, faster computers (486) were available. Since 486 computers run TRACON at a noticeably faster rate than 286's, this necessarily changed the nature of the test conditions between these groups.

Additionally, the Technical Center employees were tested using the updated version of TRACON II, which allows for the "exit after crash" option to be turned off so that the scenario can be run to completion. The TRACON version used with the aviation students did not allow this option. With this version, the scenarios end following a crash, and subsequent data can not be collected. As a result, some pieces of information for the student participants were not available. Crashes occurred for two of the students during testing, thus eliminating the ability to obtain total session scores. Given the different circumstances under which the two groups of non-controllers were tested, their data are reported separately.

Participants from Mercer College had more flexibility with their schedules and were able to spend more time in distributed training sessions. The participants from this group who had participated in the prior study, completed at least two training sessions of 1 to 1-1/4 hours each to become reacquainted with TRACON and to become familiar with the experimental procedure. New students were provided with more extensive training and practice before being tested under the experimental conditions. They were given at least four sessions of training. In general, this group was observed to display little computer knowledge and typing experience. They required considerable time to become accustomed to entering control commands via the keyboard. Two participants, originally included in this group, were eliminated prior to testing because they failed to attend the appropriate number of training sessions and their performance was markedly lower than the others. (One other participant, who did participate in testing, was subsequently eliminated since he did not carry out one of the test conditions as instructed.)

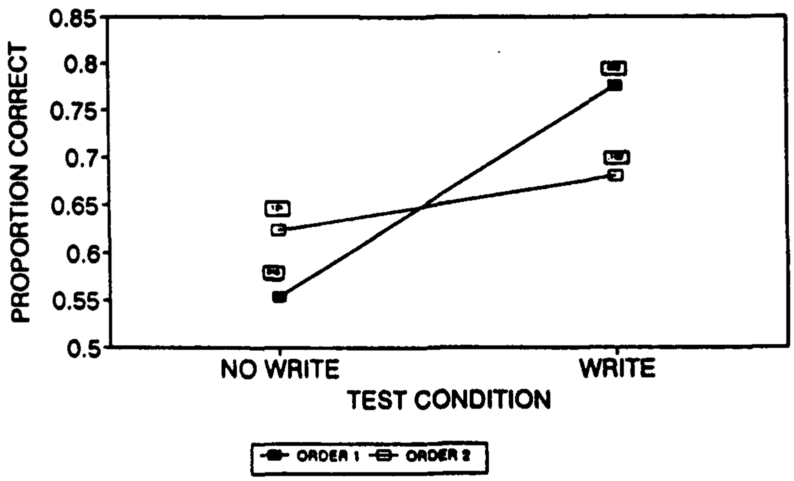
Non-controller Technical Center employees were available at various times throughout a one-week time block. The seven participants in this group were scheduled to maximize the amount of training that could be conducted simultaneously with the two computers available in the testing lab. This group completed at least three training sessions of approximately 1 to 1-1/4 hours each. These sessions were distributed over 2 days. Training proceeded smoothly, since participants in this group were computer literate and had good typing skills.

Both participant groups used paper flight strips that were presented sequentially on 8-1/2 x 11 inch sheets of paper. Strip placement, therefore, could not be altered. Prior to the start of the practice and test sessions, these participants completed questionnaires, similar to those completed by controllers, to identify factors that may have additionally influenced performance (e.g., aviation experience, TRACON experience, stress level).

RESULTS.

AVIATION STUDENTS.

The aviation students' SA differed significantly between the WRITING and NO WRITING conditions, $F(1,6)=15.40$, $p<.01$, (see figure A-1). This group's SA improved when they were allowed to write notes on the strips.



Note. Standard deviations above each data point.

FIGURE A-1. MEAN SA SCORES FOR STUDENTS AS A FUNCTION OF CONDITION AND TEST ORDER.

The effect of ORDER was not significant, $F(1,6)=.03$, $p>.05$, nor was the interaction of ORDER x CONDITION, $F(1,6)=5.45$, $.05<p<.10$. Performance SCORES for this group also did not differ significantly as a function of CONDITION, nor as a function of ORDER or the ORDER x CONDITION interaction ($p>.05$).

With respect to the post-session questionnaire variables, this group indicated that flight strips were significantly more helpful in getting them to remember information (MEMORY) about aircraft in the WRITING condition, $F(1,6)=8.87$, $p<.05$. Neither the effect of ORDER nor the ORDER x CONDITION interaction were significant, $p>.05$.

For other variables, only the secondary main effect, ORDER, and the ORDER x CONDITION interaction were found to be significant. A significant effect of ORDER indicates that the two subgroups of participants differed from one another on the measure tested. Since participants were randomly selected to work under one or the other condition first, this result was not expected and it is not obvious why it should occur. One possibility is that having worked under one condition first influenced the way in which each group managed the second. A significant ORDER x CONDITION interaction indicates more directly that the measure was influenced by the sequence in which the conditions were conducted. A significant interaction may indicate a practice effect, for example, if measures for each group's first test condition differed from their second.

For students, the effect of ORDER was significant for the CONTROL variable, $F(1,6)=9.89$, $p<.05$. Students who worked under the WRITING condition first, reported that flight strips were less useful in helping them control traffic than did those who worked under the NO WRITING condition first.

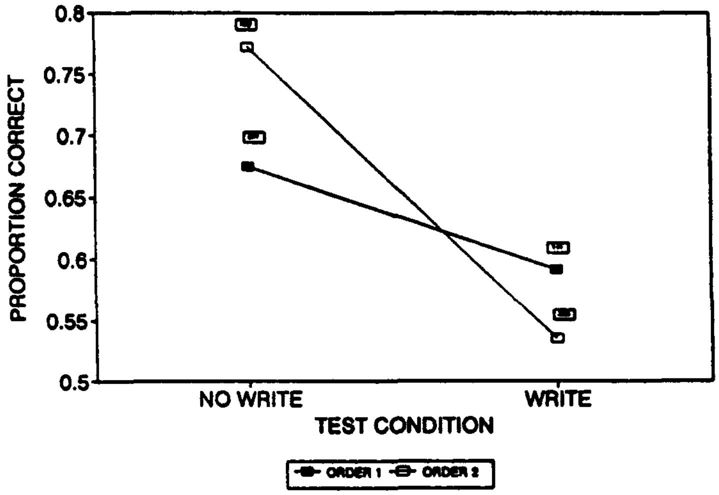
The effect of ORDER was also found significant for the FATIGUE variable, $F(1,6)=6.53$, $p<.05$. Students who worked under the WRITING condition first, reported a lower level of fatigue overall. None of the other post-session questionnaire variables differed significantly as a function of CONDITION, ORDER, or their interaction ($p>.05$) for the STUDENT group.

As far as the preliminary questionnaire variables were concerned, two variables, level of reported stress and level of reported vision, were significantly correlated with SA in the NO WRITING condition. Partial correlations indicated an inverse relationship between SA and level of reported stress (-.49, $p<.05$) and between SA and level of reported vision (-.78, $p<.05$). Improved situational awareness was associated with lower levels of stress, a result also obtained in the prior experiment. Participants who indicated lower levels of stress were those who had displayed better performance. Improved SA was also associated with lower levels of reported vision under this condition. This relationship is counterintuitive and it is not obvious what this result may mean. None of the preliminary questionnaire variables correlated significantly with performance SCORE in this condition.

As for the WRITING condition, none of the aviation student's preliminary questionnaire variables were found to correlate with SA ($p>.05$). However, number of flight hours was found to correlate significantly with performance SCORE (+.97, $p<.001$). The greater the amount of flight experience, the higher the performance level achieved under this test condition.

<u>TECHNICAL CENTER EMPLOYEES</u>.

The trends in the results obtained for this group appeared very different from those observed for the students (see figure A-2). SA decreased significantly for this group under the WRITING condition, $F(1,5)=7.85$, $p<.05$. Neither the effect of ORDER, $F(1,5)=.05$, $p>.05$, nor the interaction of ORDER x CONDITION, $F(1,5)=1.80$, $p>.05$, were significant. Performance scores did not differ significantly as a function of CONDITION, ORDER, or the ORDER x CONDITION interaction, $p>.05$.



Note. Standard deviations above each data point.

FIGURE A-2. MEAN SITUATIONAL AWARENESS SCORE FOR EMPLOYEES AS A FUNCTION OF CONDITION AND TEST ORDER.

For this group, WORKLOAD differed significantly between the test conditions, $F(1,5)=12.76, p<.05$. Participants rated their workload level higher in the WRITING condition than the NO WRITING condition. The main effect of ORDER was not significant, $F(1,5)=1.01, p>.05$. Nor was the ORDER x CONDITION interaction significant, $F(1,5)=5.90, p>.05$.

Performance assessment also differed significantly between the test conditions, $F(1,5)=7.10, p<.05$. Overall, these participants gave themselves lower ratings on their performance in the WRITING condition than the NO WRITING condition. The main effect of ORDER was not significant, $F(1,5)=.43, p>.05$. However, the interaction of ORDER x CONDITION was significant, $F(1,5)=12.14, p<.05$. Planned contrasts indicated that participants who worked under the WRITING condition first, reported a lower performance level in the WRITING condition than did those who first worked under the NO WRITING condition, $F(1,5)=22.06, p<.01$. None of the other main effects or their interactions were significant for this group, $p>.05$.

As for the preliminary questionnaire variables, partial correlations indicated that stress was inversely related to SA (-.78, $p<.05$) under the NO WRITING condition, as had been found for the student group. Higher SA was associated with lower levels of reported stress. In addition, motivational level correlated significantly with this group's performance SCORE (-.91, $p<.01$). Participants who indicated a higher level of motivation performed better that those who reported lower levels. (A negative correlation was found because this item was worded in such a way that a low value indicated high motivation, and a high value indicated low motivation.)

For the employees, none of the preliminary questionnaire variables was found to correlate significantly with SA or SCORE under the WRITING condition.

DISCUSSION.

The aviation students' situational awareness improved when they were allowed to use flight strips to record notes. Their self-assessment ratings, as indicated on the post-session questionnaire, also suggested that they found writing on flight strips valuable for helping them remember information about aircraft.

The Technical Center employees demonstrated a lower level of situational awareness when they were required to use strips for note-writing. Their subjective reports also indicated that they had a very difficult time working under this condition. Their self-assessment ratings were lower, and their workload levels were higher, when they were required to write notes. This group seemed overwhelmed by having to control traffic and keep notes on strips at the same time.

The trends in the results differed between these two non-controller groups. It is likely that differences between their practice schedules and the testing equipment used changed the nature of the task. One interpretation of the differences in results is that note-writing on strips is helpful to novices once they have had the opportunity to effectively incorporate it into their operating procedure. The aviation students, who had their practice and training sessions distributed over the course of several days, may have had a better opportunity to integrate flight strip management with control tasks than the employee group. Students may have been able to figure out how to use flight strips to their advantage, while the employee group may not have had the opportunity to combine both tasks effectively and found the additional writing task burdensome and detrimental to the primary job of controlling aircraft.

APPENDIX B

TRAINING MATERIALS

PERI/FAA

MEMORY STRATEGIES

TRAINING

MANUAL

JANUARY 1992

TRAINING MANUAL FOR TESTING

COMMONLY USED TERMS, ACRONYMNS AND ABBREVIATIONS ON FLIGHT PROGRESS STRIPS.

What is a "Flight Progress Strip?"

A flight progress strip is a written record of an aircrafts performance as it either takes-off, lands or overflies the airspace controlled by the controller <u>(YOU)</u>. A typical flight plan follows:

SK234 707	250K	00 01	100		MIDDS V165 DOWNE LAX	TWR

WHAT DOES THIS MEAN?????

SK234 ---Scandinavian Airlines flight number 234
707------Type of aircraft. A Boeing 707
250k-----Airspeed 250 knots
0001-----Time of arrival into problem
100'-----Altitude 10,000 feet.(The last two zeros are always dropped in a flight plan.

MIDDS----- An intersection of two routes used by pilots when they navigate.
V165------ A highway in the sky. Victor 165
DOWNE----- Another intersection.
LAX Twr--- The airport of intended landing, Los Angeles.

<u>PENDING</u> Flight progress strips or <u>flight plans</u> that are inactive. The "pending" file will appear about five minutes prior to the flights needing control action.
(PENDING FILES ARE BLUE)

<u>ACTIVE</u> Flight progress strips or <u>flight plans</u> that are active and under your control.
(ACTIVE FILES ARE GREEN)

<u>SELECTED</u> Flight progress strip that you are currently issuing instructions to.
(SELECTED FILES ARE BLACK)

<u>TWR</u> (Tower) Flight plans indicating "TWR" are aircraft destined to land at the airport or "twr" specified. Those airports are:
LAX-----Los Angeles
VNY-----Van Nuys
LGB-----Long Beach
TOA-----Torrance
SMO-----Santa Monica

CTR (Center) Flight plans indicating "CTR" are aircraft overflying the Los Angeles airspace enroute to another "ctr" sector. All identifiers for "ctr" control have five (5) letter characters. e.g. MIDDS, HASSA

T/O. (Take-off) Flight plans indicating "T/O" are aircraft taking off from one of the airports indicated under "twr". These aircraft are going from a "twr" to "ctr" environment.

* (Asterisk) Flight plans having an "*" in front of the routing indicates that control action on that flight plan is needed.

CONTROL ACTIONS NECESSARY TO SAFELY MANAGE TRAFFIC IN THE LOS ANGELES SECTOR

1). OVERFLIGHTS Route of flights that start with a five letter identifiers such as MIDDS and end with "Ctr". You must take a hand-off from the center controller when the aircraft flashes or blinks at you, monitor the aircrafts flight through your airspace, protecting it from other flights at the same altitude and initiate a hand-off to another center controller when the flight is five (5) miles or less from the last five letter identifier or sector boundary.

RULES;
1. Take hand-offs as soon as possible
2. Keep other aircraft at the same altitude at least 3 miles away from each other.
3. If aircraft are less than 3 miles from each other, you must have at least 1,000 ft. separation between aircraft.
4. Make final hand-off when the flight is five miles or less from the sector boundary.

2). DEPARTURES Route of flights that start with T/O and end with "Ctr". These aircraft are on the ground (pending) at the various airports waiting for you to release them (activate the flight plan). Departure aircraft need to be released, separated from other active traffic, monitored to a point five miles from the sector boundary (last five letter identifier) and then handed-off to the next center controller.

RULES; 1. Release aircraft as soon as possible.
2. Make sure you have at least 3 miles vertical or 1,000ft. horizontal separation from all other traffic in your sector.
3. Insure that aircraft are at the flight planned altitude prior to making your hand-off.
4. Insure that aircraft are going to the proper exit fix.
5. Make final hand-off when the flight is five miles or less from the sector boundary.

3). <u>ARRIVALS</u> Route of flights that end with "Twr". These aircraft are the most difficult to control since you must take a hand-off from the center controller, radar vector or maneuver the aircraft to the appropriate final approach fix, descend the aircraft to the proper altitude, turn the aircraft on the final approach course and clear the aircraft to contact the tower.

RULES; 1. Take hand-offs as soon as possible
2. Make sure you have at least 3 miles vertical or 1000 ft. horizontal separation from all other aircraft in your sector.
3. Descend aircraft to the proper final descent altitude.
4. Radar vector or maneuver the aircraft towards the final approach course,
5. Turn aircraft on to the final approach course outside the final approach fix (F.A.F.) on a heading no greater than thirty degrees from the final approach heading as indicated on the airports chart.
6. Make final hand-off to the tower prior to the F.A.F.

4). <u>TOWER EN-ROUTES</u> Route of flights that start with T/O and end with "Twr".These aircraft are on the ground at one airport, waiting to take off and land at another airport in your sector. You must release or activate the flight as indicated under DEPARTURES, and then follow the instructions pertaining to vectoring as listed in ARRIVALS.

RULES: 1. Release the aircraft as soon as possible.
2. Follow instructions under ARRIVALs listed above.

COMMONLY USED TERMINOLOGY

Request Vector-----Aircraft is requesting assistance to the airport or to a navigational fix.

Request descent----- Aircraft is getting close to the airport of intended landing without having had a clearance to descend to the final approach altitude.

Request release----- Tower controller is asking permission for a flight at his/her airport to fly into your sector under instrument flight rules.

Missed approach---- Aircraft that you cleared for an approach at one of your airports cannot make a safe landing due to being either too high , too close to the airport, too far away from the final approach course, or being at the wrong altitude.

Not on my scope yet--- Center controller reminding you that you are handing the aircraft off outside the 5 mile parameter recognized by the game.

HOW TO COMMUNICATE TO AIRCRAFT AND OTHER CONTROLLERS

In order to communicate to aircraft or other controllers, you must take three specific steps.

STEP ONE----- SELECT AN AIRCRAFT.

When an aircraft, control tower or center controller wants you to assume control of an aircraft (or select the aircraft), you'll hear the request, see the aircraft blinking at you and see the request written on your PC at the bottom of your screen. (Pink area) You can select the aircraft by either of the following means.

a) Scroll ARROW UP or ARROW DOWN to HIGHLIGHT THE AIRCRAFT, THEN PRESS THE ENTER KEY.
b) TYPE THE AIRCRAFT IDENTIFICATION When the App/Dep. prompt appears in the pink area, THEN PRESS THE ENTER KEY.

You now have selected the aircraft that you wish to control.

STEP TWO------- ISSUE A COMMAND INSTRUCTION.

Issue to your selected aircraft the appropriate command instructions as listed in the AIRCRAFT SELECTED COLUMN below.

(KEYBOARD ENTRIES)

KEY	AIRCRAFT SELECTED	NO AIRCRAFT SELECTED
ARROW UP-------	Climb and maintain ____	Scroll up
ARROW DOWN-----	Descend and maintain_____	Scroll down
ARROW LEFT-----	Turn left_____	***************
ARROW RIGHT----	Turn right_____	***************
BACKSPACE------	Disregard previous command	Cancel last entry
SPEED ---------	Change speed to _____	*****************
DIRECT TO -----	Cleared direct to ______	*****************
SAY HEADING----	Say heading and airspeed	*****************
RESUME NORMAL--	Resume speed and own navigation	*****************
HAND-OFF-------	Hand-off to CTR or TWR	*****************
HOLD AT -------	Hold at (designated fix)	*****************
ENTER----------	Release traffic on ground Take hand-off from center	Select aircraft (most important)
SEMI-COLON (;)-	To issue multiple commands e.g. Command (;) Command	*****************
PLUS (+)-------	Zoom in	*****************
MINUS (-)------	Zoom out	*****************
SLANT (/)------	Move aircraft leader to------	*****************

STEP THREE-----Define the specific parameters such as altitude or heading using the numbers functions on the left keyboard.

ALTITUDE----The last two digits of the altitude are always omitted.
e.g. 19 means 1900ft., 120 means 12,000ft.

HEADING-----To turn to a specific number of degrees use two digits.
e.g. 20 means alter heading twenty degrees.
To turn to a specific heading use three digits.
e.g. 020 means heading Zero Two Zero degrees.

HOW TO TAKE A RADAR HAND-OFF AND RELEASE A DEPARTURE AIRCRAFT.

This process only requires two steps.

Step One----Select the aircraft and hit the ENTER KEY
Step two----Depress the ENTER KEY for the second time.

OTHER INFORMATION KEYBOARD ENTRIES.

These entries are provided for your information and are useful to obtain additional information.

ALT+F----- To gain access to the TRACON menu.
ARROWS---- To move left or right, up or down in the menu.
TAB------- To move the cursor into a different field.
ESC------- To cancel last entry.
CTRL+F---- To show the aircrafts flight plan route.
CTRL+T--- To show the Airport information.
CTRL+A---- To show aircraft performance characteristics.

TO ACTIVATE ANY INFORMATION REQUESTS YOU MUST FOLLOW-UP BY DEPRESSING THE ENTER KEY.

HOW TO MAXIMIZE YOUR SCORING.

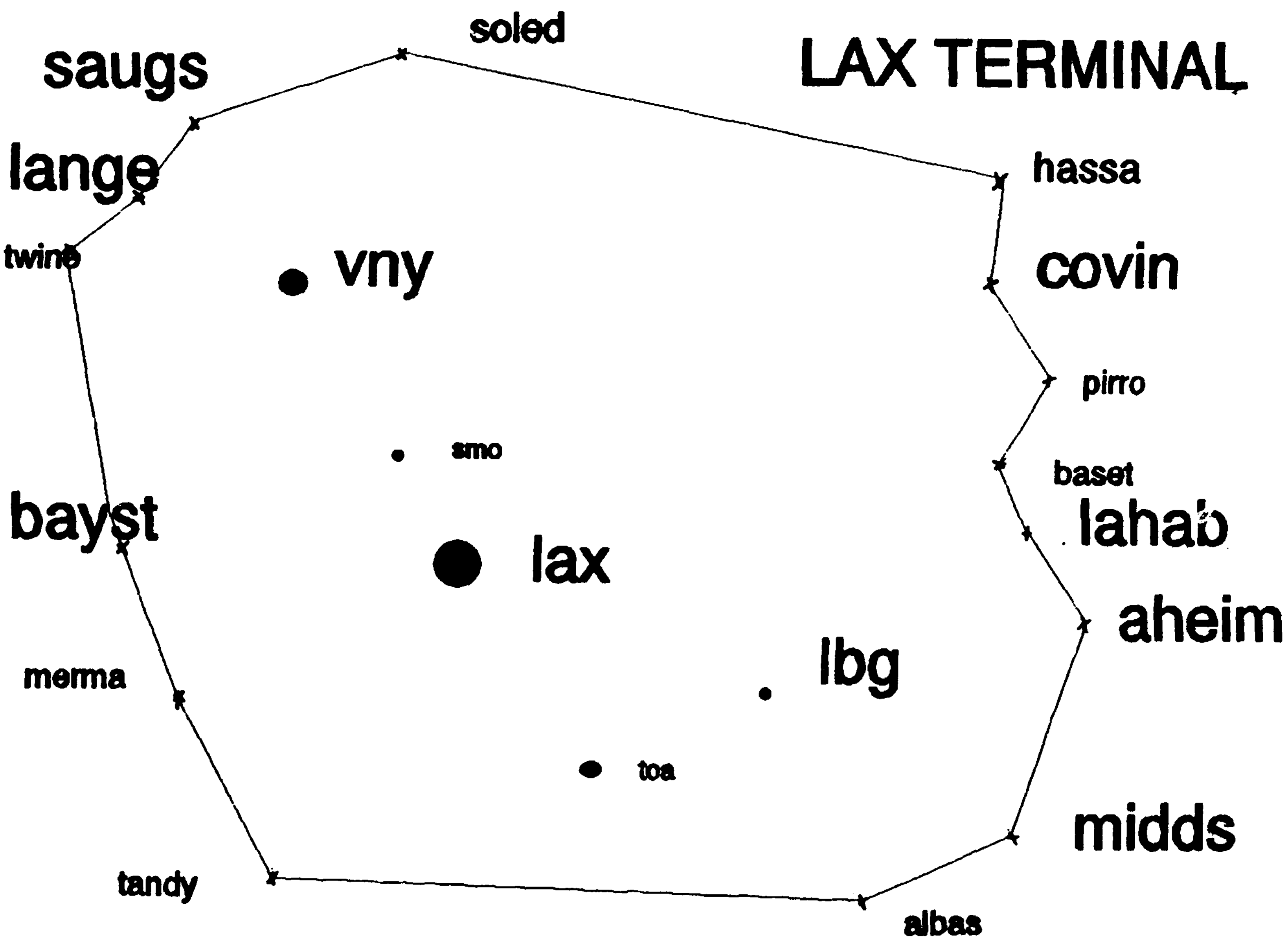
1) Take hand-off's as soon as possible.
2) Keep all aircraft at the same altitude at least 3 miles or 1,000 feet away from each other.
3) Turn aircraft on to the final approach course outside of the approach gate or course indicator.
4) Hand-off aircraft no sooner than 5 miles from the sector boundary.
5) Don't turn or maneuver aircraft unnecessarily.
6) Don't forget to make hand-off's to the next center controller.
7) Turn aircraft onto the approach course at the proper altitude and at a heading that does not differ by more than thirty degrees from the heading on your chart.
8) Release departure aircraft as soon as possible.
9) Try to issue multiple commands using the (;) to allow you to control the frequency.
10) DON'T AIM TWO AIRCRAFT AT EACH OTHER. A COLLISION IS AN AUTOMATIC EXIT FROM THE TEST.

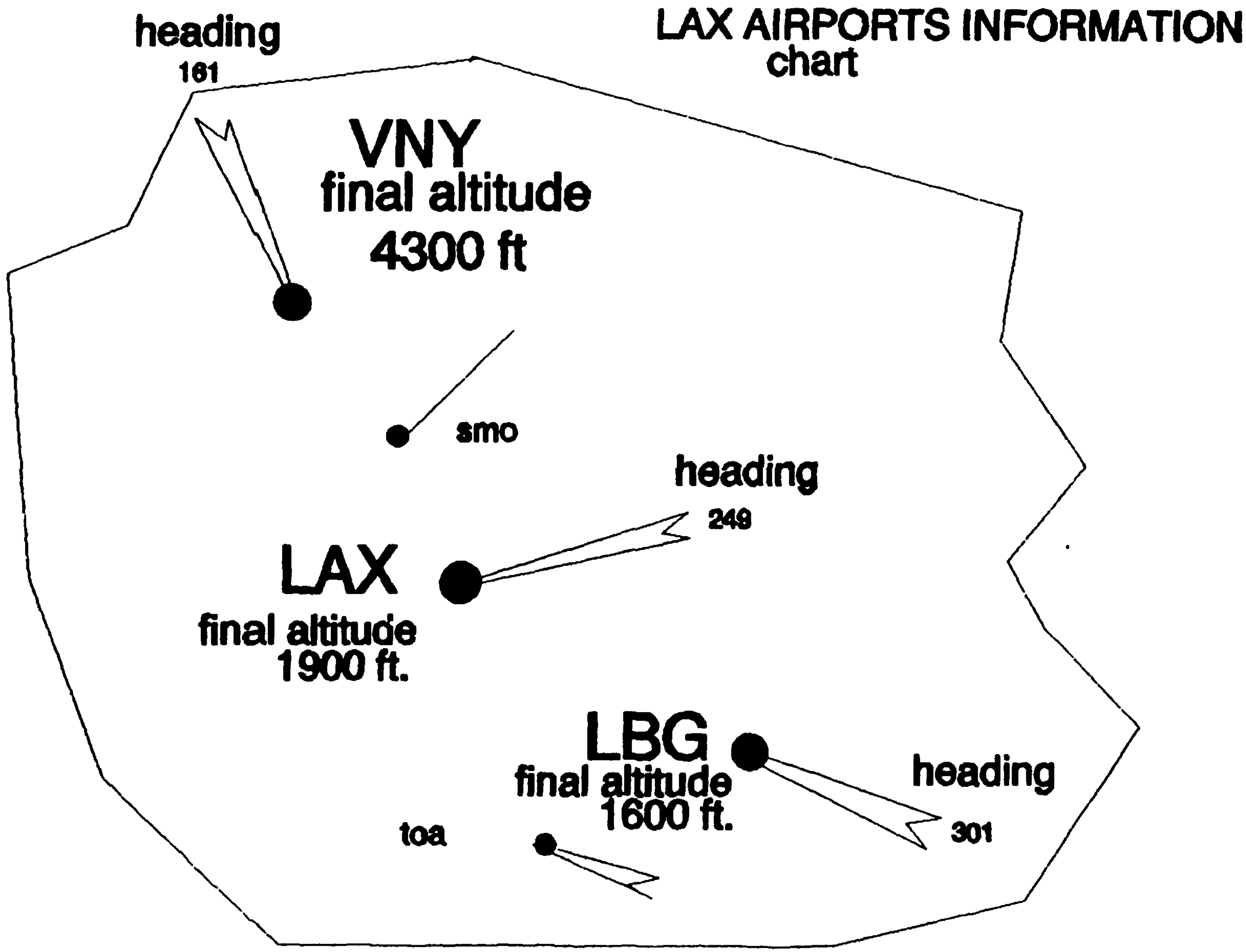
This testing material will be fully explained to you by your instructor who was a qualified Air Traffic Controller. Feel free to ask any questions about the information hand-out, Air Traffic Control in general, or memory strategies we hope to teach you.

Remember, we expect you to make mistakes. We want you to have "FUN". Try to do your best but don't worry if you get behind or can't remember everything. You are not expected to become Air Traffic controller after this experiment.

Thanks again for your volunteer participation.

The staff at PERI.


LAX TERMINAL
soled
saugs
lange
twine
vny
smo
bayst
lax
memma
lbg
toa
tandy
albas
hassa
covin
pirro
baset
lahab
aheim
midds


LAX AIRPORTS INFORMATION
chart
heading
161
VNY
final altitude
4300 ft
smo
heading
249
LAX
final altitude
1900 ft.
LBG
final altitude
1600 ft.
heading
301
toa

function commands

(insert)

(home)

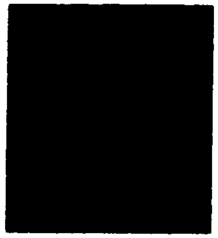
(page-up)

(delete)

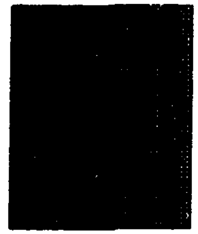
(end)

(page down)

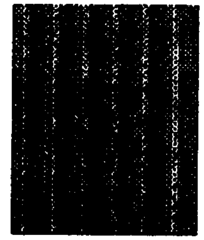
control instruction commands



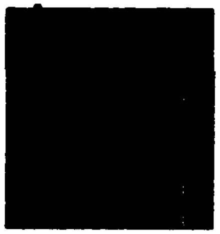
7



8

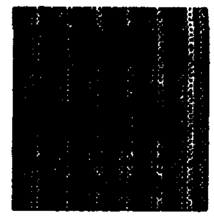


9



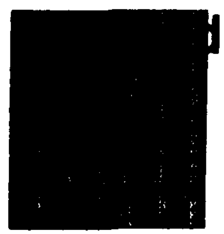
4

5

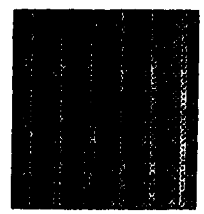


6

1



2



3

HOW TO COMMUNICATE TO AIRCRAFT

STEP ONE..Highlight the strip (ENTER)
STEP TWO.. Issue the Command (ENTER) (if necessary)
STEP THREE.. Define the parameters (ENTER)

KEY PAD CONTROL COMMANDS

COMMAND	KEYPAD
Turn Right	→
Turn left	←
Degrees	00
Heading	000
Climb and Maintain	↑
Descend and Maintain	↓
Change Speed to..	SPEED
Resume Nrml Nav...	RESUME NORMAL
Cleared Direct to..	DIRECT TO
Hold at...	HOLD AT
Handoff to Twr/Ctr..	HAND-OFF
Say Heading and Speed..	SAY HEADING
Release Twr Depts.. Take Ctr Hand-offs..	ENTER
Make Multiple Commands..	(:)
Move Leader to....	(/)

AIRPORT INFORMATION

IDENT	HEADING	ALTITUDE	FIX
LOS ANGELES (LAX)	249	1900	DOWNE
LONG BEACH (LGB)	301	1600	MIDDS

IMPORTANT FLIGHT STRIP INFORMATION

CTR... OVERFLIGHT e.g. (MIDDS) ↔
TWR... ARRIVAL e.g. (LAX) ↓
T/O... DEPARTURE FROM...... ↑
(*)... AIRCRAFT IS READY FOR YOU TO TAKE IMMEDIATE ACTION

MUSTS

Take hand-offs A.S.A.P.
Keep aircraft ¼ to ½ inch apart (3 miles)
Make hand-offs no sooner than 5 miles (½) inch from boundary
Use proper altitudes for Arrival approach clearances
Only clear one aircraft for Take-off at a time. Let the second one wait one minute.

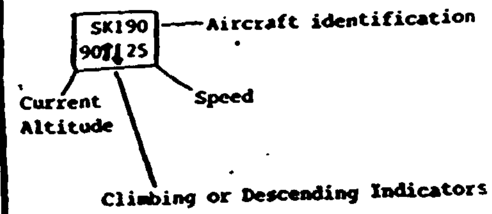
MOST IMPORTANT

YOU MUST ALWAYS USE "ENTER" after you type your command otherwise the command will not be processed.

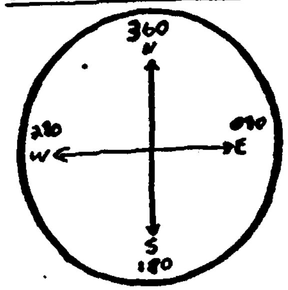
KEYBOARD INFORMATION ENTRIES

REQUEST	KEYPAD
Access Menu	ALT+F
Move in menu	ARROWS
Different field	TAB
Cancel or Delete	ESC or BACKSPACE
Flight plan Info.	CTRL+F
Airport Info.	CTRL+T
Aircraft Info.	CTRL+A

DATA BLOCK INFORMATION



COMPASS ORIENTATION



APPENDIX C

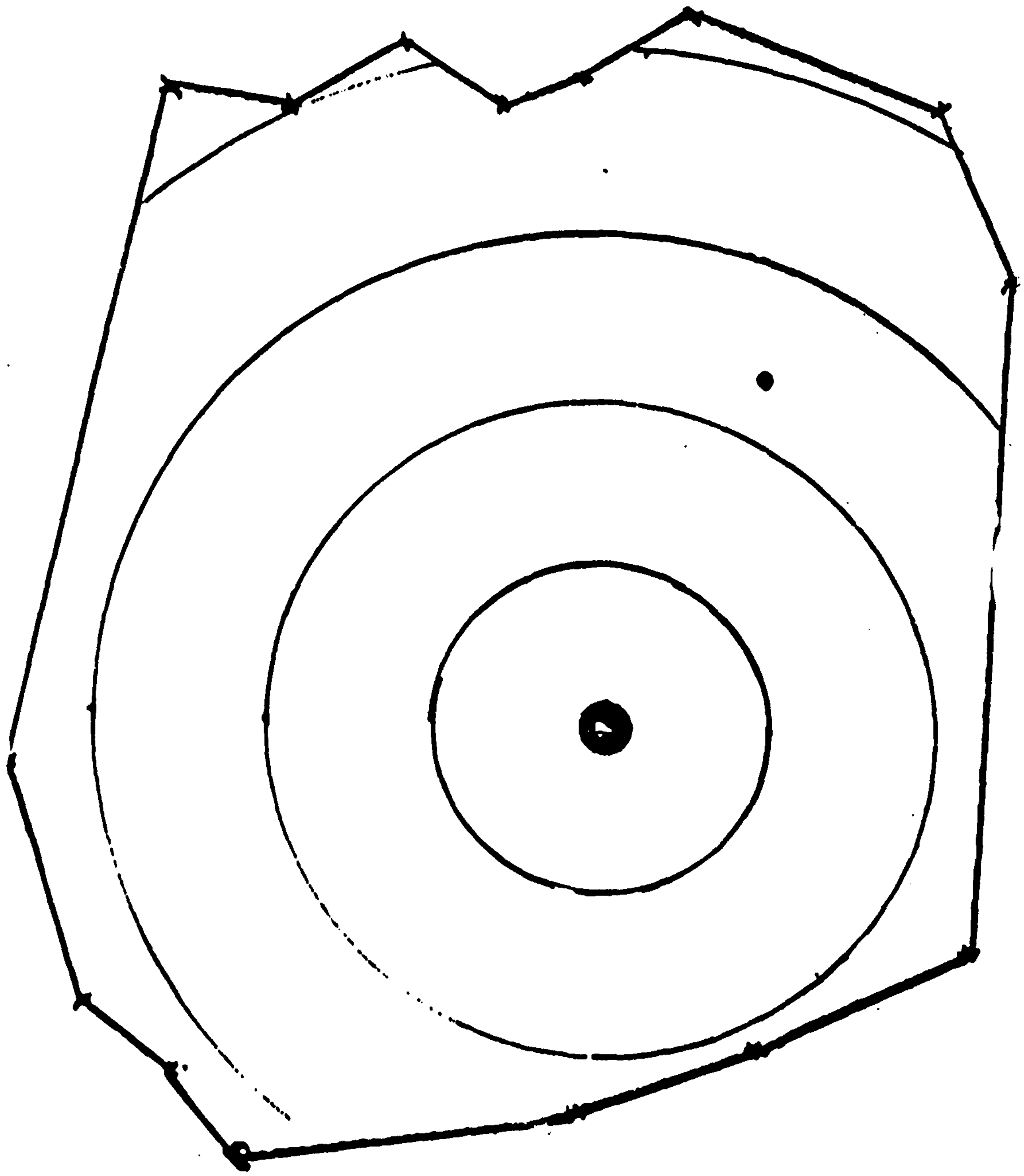
FLIGHT STRIPS AND RESPONSE FORMS

AC217 725	COVIN LAX	↓	120
UA989 747	AHEIM LAX	↓	90
N9234N PA42	LAX AHEIM	↑	90
N672P L23	LGB BAYST	↑	80
N501J PA44	SAUGS MIDDS	↔	90
DL123 727	BAYST LAX	↓	110
N369R C-425	COVIN LGB	↓	70
N99F B56	SAUGS LGB	↓	110
AL437 725	AHEIM LAX	↓	100

sheet 1 of 2

N8153 AA5	LAX / COVIN	↑	90			
N245X PA42	AHEIM / LAX	↓	100			
NW957 L10	SANGS / LAX	↓	90			
CO 76 M80	BAYST / COVIN	↔	70			
N7533N PA42	LAX / SANGS	↑	90			

sheet 2 of 2



AC217

725

UA989

747

N9234N

PA42

N672P

L23

N501J

PA44

DL123

727

N369R

C-425

N99F

B56

AL437

725

sheet 1 of 2

N815J AA5
N245X PA42
NW957 L10
CO76 M80
N7533N PA42

sheet 2 of 2

TRACON II Scoring Parameters

command/situation	point value
successful overflight	+ 500
successful departure	+ 600
successful arrival	+ 800
any command	- 10
pause	- 10000
wrong speed at handoff	- 100
wrong altitude at handoff	- 250
missed handoff	- 500
missed approach	- 250
lost aircraft off radar	- 1500
separation error (<3mile)	- 1000
separation erros (<1mile)	- 5000
crash	0
weather	- 5
pilot request (success/fail)	+/- 30
emergency (success/fail)	+/- 500

Point values added or subtracted from score for each command/situation/error. (Wesson International, 1990, p. 8-12)

APPENDIX D

QUESTIONNAIRES AND SCORING SHEETS

____

PRELIMINARY QUESTIONNAIRE

> **The purpose of this questionnaire is to find out something about your background and current feelings about this project in order to better understand your performance during the course of the study. All information will be coded. Your name will not be linked to the answers you provide.**

Your current position:____

Years in ATC:____________

Years in terminal environment:_______

Years in en-route environment:_______

Total facilities at which you have worked:______

Do you typically use strip management techniques (marking, etc.) on the job?
yes no

If yes, briefly describe what kinds of techniques you use.

____

____

____

Have you ever used TRACON II?
yes no

If yes, rate your level of proficiency

1 2 3 4 5 6 7 8 9 10
low high

Using the scale provided:

Rate your level of **computer experience.**

1 2 3 4 5 6 7 8 9 10
none extensive

Rate your level of **video game experience.**

1 2 3 4 5 6 7 8 9 10
none extensive

Rate your current **vision.**

1 2 3 4 5 6 7 8 9 10
poor excellent

Do you have a **color vision deficiency**? yes no

If so, what is it? ______________________________

I **freely volunteered** to participate in this project.

1 2 3 4 5 6 7 8 9 10
strongly disagree strongly agree

I am currently in **good health.**

1 2 3 4 5 6 7 8 9 10
strongly disagree strongly agree

During the last several months, I have been experiencing a relatively high level of stress.

1	2	3	4	5	6	7	8	9	10
strongly disagree								strongly agree	

I am not very motivated to participate in this study.

1	2	3	4	5	6	7	8	9	10
strongly disagree								strongly agree	

Identify the reason(s) why you decided to participate in these experiments.

____

____

____

CONTROL INSTRUCTIONS ISSUED

AIRCRAFT I.D.	TURNS/ HEADING	DIRECT TO	HAND OFFS	CLIMBS/ DESCENTS	SPEED RESTRNS	CLEAR APPRO	HOLD	ERROR
AC217								
UA989								
N9234N								
N672P								
N501J								
DL123								
N369R								

Name:

CONTROL INSTRUCTIONS ISSUED

AIRCRAFT I.D.	TURNS/ HEADING	DIRECT TO	HAND OFFS	CLIMBS/ DESCENTS	SPEED RESTRNS	CLEAR APPRO	HOLD	ERROR
N99F								
AL437								
N815J								
N245X								
NW957								
CO76								
N7533N								

PERFORMANCE REVIEW

Aircraft handled: ______

Total time (minutes): ______

Separation conflicts: ______

Handoff errors: ______

Missed approaches: ______

Pilot requests granted/total: ___/___

Emergencies landed/crashed: ___/___

MAXIMUM POSSIBLE SCORE: ______

YOUR SCORE: ______

Choose the one number below which best describes how hard you were working during this period:

DESCRIPTION OF WORKLOAD CATEGORY	RATING (CIRCLE ONE)
VERY LOW WORKLOAD All tasks were accomplished quickly and easily	1 2 3
MODERATE WORKLOAD The chances for errors or omissions were low	4 5 6
RELATIVELY HIGH WORKLOAD The chances for some errors or omissions were relatively high	7 8 9
VERY HIGH WORKLOAD It was barely possible to accomplish all tasks properly	10 11 12

CONTROLLER POST-SESSION QUESTIONNAIRE

PLEASE COMPLETE THE FOLLOWING QUESTIONS AS SOON AS YOU HAVE COMPLETED THE SESSION. YOUR RESPONSES SHOULD FOCUS ONLY ON THE WORK THAT YOU HAVE JUST COMPLETED IN THE LAST CONTROL PERIOD.

ALL CONTROLLERS EXPERIENCE A WIDE VARIETY OF ACTIVITY AND RESULTANT WORKLOAD DURING THEIR CAREERS. IT DOES NOT DETRACT FROM YOUR PROFESSIONALISM IF FOR A GIVEN PERIOD YOU REPORT VERY HIGH OR VERY LOW WORKLOAD. ON ALL THE QUESTIONS WHICH FOLLOW FEEL FREE TO USE THE ENTIRE NUMERICAL SCALE FOR EACH ANSWER. BE AS HONEST AND AS ACCURATE AS YOU CAN.

1. Rate your performance controlling traffic during the past session. Circle the number which best describes how well you think you did.

1	2	3	4	5	6	7	8	9	10
average									excellent

2. What fraction of the time were you busy during the period you were controlling?

1	2	3	4	5	6	7	8	9	10
seldom had much to do									fully occupied at all times

3. How much did you have to think during this period?

1	2	3	4	5	6	7	8	9	10
minimal thinking & concentration									a great deal of thinking & concentration

4. Rate the degree to which you found this control period stressful.

1	2	3	4	5	6	7	8	9	10
low									high

5. I am feeling tired.

1	2	3	4	5	6	7	8	9	10
strongly disagree									strongly agree

6. Briefly describe your strategy for working traffic during this control period.

7. If you have a choice of separating aircraft vertically (by altitude) or horizontally, which do you prefer to do and why?

8. How helpful were the paper flight strips to you in making **control** decisions for aircraft during this past session?

1	2	3	4	5	6	7	8	9	10
not at all									extremely

9. Briefly explain why the strips were or were not helpful. Compare your performance during this session to your performance in other sessions when the strips were used differently.

10. To what extent were th paper flight strips useful for helping you **remember** aircraft information when the display was blocked from view?

1	2	3	4	5	6	7	8	9	10
not at all									extremely

12. Briefly explain why the strips were or were not helpful. Describe anything else that you feel might have been helpful in getting you to remember this information more quickly or more accurately than you did.

13. Describe the strategies you used to help you remember aircraft information.

Is there anything else that happened this past session which you feel might help us understand the results? Any comments you have at this point would be very welcome.

☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 704-078/80121