Air Traffic Controller Memory Enhancement

Literature Review and Proposed Memory Aids

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16. Abstract

The Federal Aviation Administration is engaged in an ongoing research effort to help air traffic controllers reduce the frequency of operational errors. This report presents the results of the first year's efforts in a three-year project to develop practical, effective memory aids to improve controller performance of tasks where memory is a critical element. Literature on controller memory and performance is reviewed and operational errors are analyzed to determine the nature and frequency of controller memory lapses. Several potential memory aids are indentified and evaluated for effectiveness, feasability, usability, acceptability, cost, and testability. The highest ranking memory aids are recommended for futher evaluation in controlled experiments.

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EXECUTIVE SUMMARY

The air traffic control system is highly complex and very dynamic. As new hardware and software systems are developed, it is essential that we develop a clear understanding of how controller memory will be influenced. Failure to store, search and/or retrieve key elements of operational data can lead to inaccuracies of detection and/or decisions with resulting errors in the clearances issued. This report concerns the influence of controller memory lapses on operational errors.

The report presents the results of the first year's efforts in a three-year project to *enhance National Airspace System performance by developing a set of practical and effective memory aids to improve controller performance of tasks where memory is a critical element.* The focus of the effort is on the controller's tactical working memory, which has a three to five minute window. In the first year, the goal is to make maximum use of available information to analytically determine ways to enhance memory and air traffic controller performance. In the second year, selected memory aids will be evaluated in a series of empirical experiments to determine which aids will be suitable for field implementation. During the third year, the evaluation process will continue in the field operational environment to verify the laboratory test results and evaluate the acceptability of these memory aids to operational air traffic controllers and managers.

We have used a structured research strategy to define the elusive contribution of memory to ATC operational errors and the potential of memory aids to improve controller performance. The first stage was to develop an understanding of ATC tasks, operational errors, and the memory contribution to operational errors using the available literature on ATC memory and performance. In the second stage, we identified potential memory problem areas in relation to operational errors. Based on this information and a survey of the literature on job-aiding techniques and research relevant to air traffic control, we developed ideas for potential memory aids. We also used subject matter expertise and the results of a limited inquiry on job aids being used today by active air traffic controllers to identify additional ideas for memory aids. Finally, criteria for evaluating potential aids were developed. These criteria were based on the nature and purpose of this project, and were agreed upon in conversations between the contractors and the COTR. The results of each stage of the analysis are discussed in more detail below.

Human memory is thought to be composed of three subsystems: sensory storage, working memory, and long term memory (Sanders and McCormick, 1987; Wickens, 1987; Wickens, 1984). Controller tactical working memory is defined by its functional requirements, contents, organization, operational capacity and limitations. The functional requirements are (1) attention is required for sensory input to be processed into working memory, and (2) rehearsal is required to maintain the contents of working memory for the three to five minute tactical window. The contents include information such as:

- Current altitude, airspeed, heading, size and type for each controlled aircraft

  Projected altitude, airspeed, and heading based on planned tactical maneuvers

  Recent communications such as change in route of flight/altitude, clearance requests, etc.

  Weather conditions, runway conditions, navigational aids status

  Each aircraft's positions under his control in the controlled airspace, and in relation to other traffic

- Projected potential conflictions between aircraft based on the above information.

This information is hierarchically organized in working memory, with the most important items at the top (e.g., conflict or no conflict between two aircraft) and less important information below (e.g., type or speed of each aircraft). The items are probably chunked in some fashion. The number of aircraft being controlled probably determines chunking strategy (Bisseret, 1971). The controller's operational strategies determine the sequence of mental operations and the number and kinds of data used in those operations

(Sperandio, 1971, 1978). Information is also organized to project future states of aircraft (Bisseret, 1971).

The capacity of working memory is 7 $\pm$ 2 chunks of information (Miller, 1956). Interference due to similarity between items (e.g., similar call signs), proactive and retroactive inhibition affect search and retrieval from working memory (Wickens, 1987; Fowler, 1980). The demand on the controller's attentional resources to update working memory contents is quite high. The controller's training, procedures in use, and preferred control strategies will affect storage, search and retrieval functioning.

In order to understand how controller memory lapses occur, we adapted a model of cognitive control of behavior to air traffic controller performance. The model is based on Rasmussen's (1982, 1986) model of cognitive functioning for operators of complex systems. We used it to provide a framework and logical link between operational errors, cognitive errors and their memory components, and job aids that are appropriate for each cognitive level of performance. The model is hierarchically related to a decreasing familiarity with the environment. At each level, certain kinds of cognitive errors can occur due to human variability or inappropriate adaptation to system changes. At the lowest level is skill-based behavior (most familiar environment), governed by sensorimotor schema, and consisting of automatic, over-learned behaviors such as rolling the trackball to a target and marking flight strips. At the next level, rule-based behavior, the controller recognizes a situation and associates it with a stored rule or procedure for executing the tasks. At the highest level, knowledge-based performance, the controller must analyze the environment, form a goal and develop a plan or strategy. Each of these levels of cognitive control of behavior and their associated cognitive errors were related to specific types of operational errors. Operational errors were classified based on Kinney, Spahn and Amato's (1977) analysis of controller and supervisor performance. Operational error categories include:

Controlling aircraft in another's airspace
(2) Processing flight data manually inter/intra-facility
(3) Inter/intra-facility coordination
(4) Assuming separation will exist
Improper radar/visual scanning

(6) Inappropriate phraseology/voice communications

(7) Overuse of automation (NAS dependence).

The frequency of operational errors were examined using a sample of NASA's Aviation Safety Reporting System reports. Because the reports are submitted voluntarily, the underlying population is unknown and valid statistics cannot be reported. For this reason, a further analysis of FAA Operational Error Report Profiles was undertaken and will be submitted under a separate cover.

Using the controller cognitive model, operational errors were analyzed to determine the contribution of memory lapses to these errors. For each type of operational error and its associated memory component, we identified potential memory aids. Ideas for memory aids came from a review of the available literature on job aiding functions in general, and research on job aids for air traffic control. We also reviewed studies and papers on the effect of increased automation on controller performance. The authors contended that poorly designed increases in automation force the controller into a monitoring mode, and do not allow for flexible control strategies. Thus, we incorporated the goals of keeping controllers active and in the control loop, while allowing for flexibility, into our proposed job aids. Finally, job aids were evaluated against subjective criteria, with the objective of recommending certain job aids for testing in the second year of this project.

The major conclusion of this study is that reliability of air traffic controller memory is a significant problem affecting aviation safety and efficiency of the National Airspace System. Identification of practical, effective memory aids is the first step toward the solution to this pervasive problem.

SECTION 1.0 INTRODUCTION

1.1 Background

The FAA has become increasingly concerned about actual and potential operational errors of air traffic controllers. In April 1987, an FAA Administrator's task force on ATC operational errors identified a number of factors that contributed to the nature and frequency of controller errors. Two areas in particular were highlighted by an operational error analysis work group. These were controller memory lapses and controller information scanning. This report concerns controller memory lapses.

The air traffic control system is highly complex and very dynamic. As new hardware and software systems are developed, it is essential that we establish a clear understanding of how controller memory will be influenced. Each controller is exposed to a virtual river of information which flows through his/her work station at a pace that he/she cannot control. In order to manage the airspace within his/her domain, a certain amount of this information must be captured and retained primarily for tactical (three to five minute) use and secondarily for strategic planning, which is a concept still in its infancy for air traffic control. Memory is one of a number of elusive constructs within the human performance equation. It can never be observed directly and must be inferred based on environmental cues and the behavior of the individual operator.

Given current technology, the human operator must learn and retain critical information or he/she must establish a strategy for obtaining what is needed in the here and now. Failure to store, search, and/or retrieve key elements of operational data can lead to inaccuracies of detection and/or decisions with resulting errors in the clearances issued. Until now, there has been no clear documentation concerning the memory demands placed upon controllers in their daily activities. The purpose of this project is to make maximum use of available information to analytically determine the nature and extent of air traffic controller memory lapses in the current National Airspace System (NAS).

1.2 Objectives

The objective of this three year project is to *enhance NAS system performance by developing a set of practical and effective memory aids to improve controller performance of tasks where memory is a critical element.*

To accomplish this objective, controller tasks and operational errors have been analyzed in the first year to develop an understanding of the role memory plays in controller performance (Table 1). With that knowledge, various memory aids were evaluated to identify those that have potential to improve controller performance.

The focus of this effort is on the controller's tactical working memory, which has a three to five minute window. Tactical memory includes information such as aircraft call signs, headings, altitudes, and weather information. A more complete definition of tactical working memory will be provided later in this report. The report discusses the methodology and results of the first year's effort to identify potential memory aids. The technical approach used to analyze the memory literature review and operational error reports is provided in the next section.

In the second year, selected memory aids will be evaluated in a series of empirical experiments to determine which aids will be suitable for field implementation. Experiments will be conducted under controlled laboratory conditions at the PERI and FAA Technical Center facilities to evaluate and refine proposed memory aids. During the third year, the evaluation process will continue in the field operational environment to verify the laboratory test results and evaluate the acceptability of these memory aids to operational air traffic controllers and managers.

TABLE 1. SCHEDULE

YEAR ONE	YEAR TWO	YEAR THREE
EXAMINE WAYS TO ENHANCE MEMORY AND ATC PERFORMANCE	CONDUCT EVALUATION EXPERIMENTS	CONDUCT DEMONSTRATION/ EVALUATION FIELD TRIALS
o DEVELOP UNDERSTANDING OF MEMORY IN CONTROLLER PERFORMANCE	o SELECT CANDIDATE MEMORY AIDS	o PREPARE MEMORY AIDS
o IDENTIFY MEMORY PROBLEM AREAS	o PREPARE PROTOTYPES	o DEVELOP IMPLEMENTATION PROCEDURES
o IDENTIFY POTENTIAL MEMORY AIDS	o DEVELOP RESEARCH DESIGN	o CONDUCT DEMONSTRATION/ VALIDATION AT FOUR SITES
o EVALUATE POTENTIAL MEMORY AIDS	o CONDUCT EMPIRICAL EXPERIMENTS	

SECTION 2.0 METHOD

A structured research strategy has been used to define the elusive contribution of memory to ATC operational errors and the potential of memory aids to improve controller performance. That strategy consists of several stages with cross checks and feedback to assure the credibility of the conclusions and the resulting memory aids. The first stage was to develop an understanding of ATC tasks, operational errors and the memory contribution in controller tasks; memory is ever present, but unmentioned as a factor in job performance and operational errors. The second stage, therefore, was to expand the analysis to include memory as an active element. The third stage was to develop concepts of memory aids. And the fourth stage was to refine the memory concepts and select candidates for experimental evaluation.

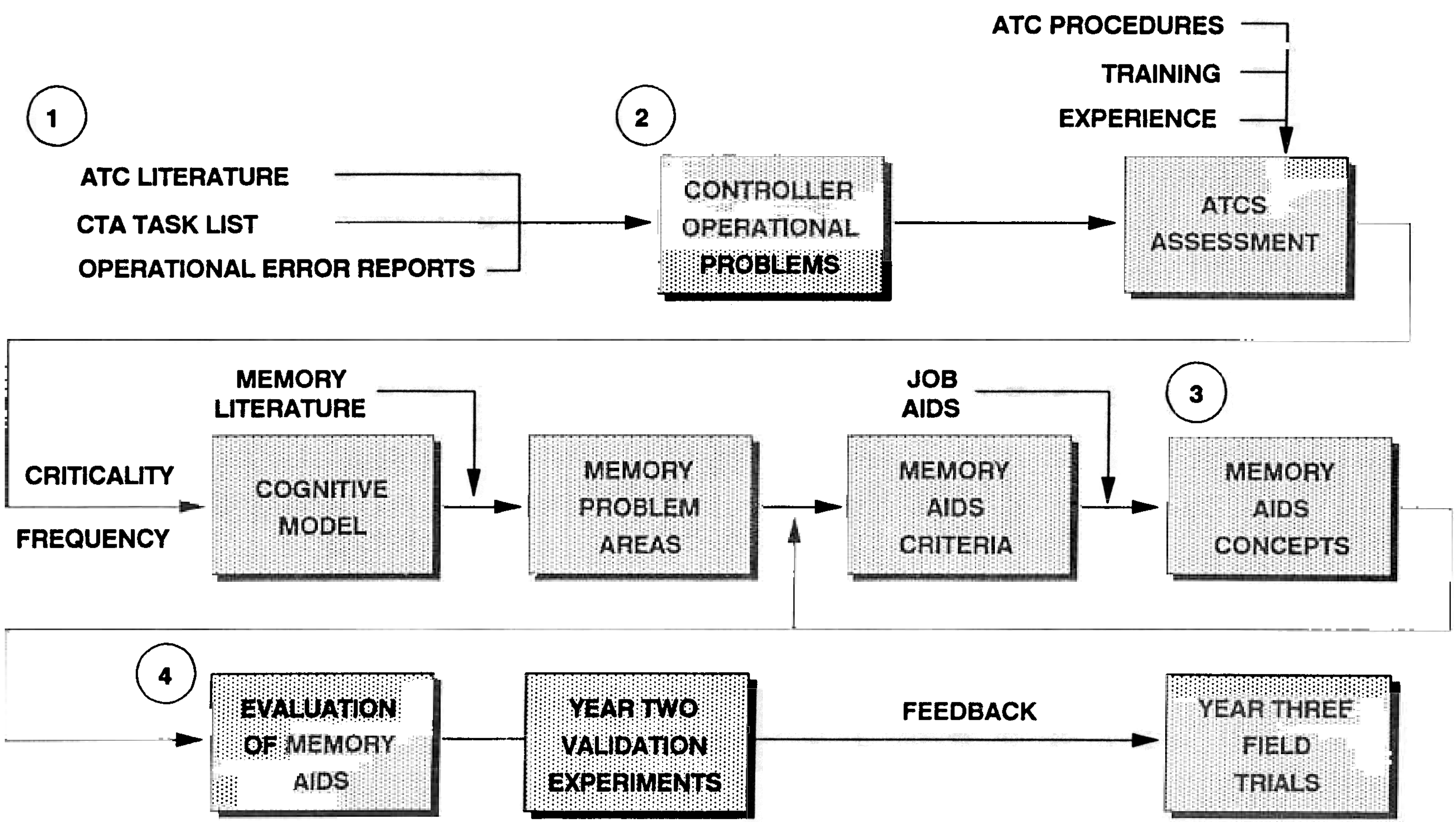
The conceptual baseline for this work is an understanding of the controllers' task performance with the current National Airspace System (NAS) equipment. Controller task analysis and performance data provide the factual data for the baseline. However, the role of memory is not well-defined in the operational error reports or literature. The literature suggests a number of factors that may impair information processing or lead to memory lapses, but does not provide a clear cut relationship between specific kinds of memory problems and operational errors. Therefore, the relation of memory to identified operational problems has been developed by an analysis of selected critical tasks by an experienced air traffic control specialist (ATCS) working in conjunction with a research psychologist.

The analysis was accomplished in a series of steps shown in Figure 1 and which are described below.

2.1 Step 1: Develop Understanding of Memory in Controller Performance

The first step in the analysis of the short term memory load placed on air traffic controllers involved a search and review of the available literature on controller memory

FIGURE 1. OVERVIEW OF TECHNICAL APPROACH



and performance. The literature was obtained from the FAA's Technical Center library and from the contractor's extensive Behavioral Science library. (Literature review findings are presented in the next major section of this report.) Key words such as "controller performance," "memory," "cognitive strategies," "workload," and "controller errors" were used to search the literature. The literature included technical reports, journal articles, incident/accident data and operational error data. Each document was reviewed and pertinent findings and conclusions were abstracted on a summary form. At the same time, controller task analysis data (Ammerman, Fligg, Pieser, Jones, Tischer, & Kloster, 1983) was reviewed to develop a greater understanding of controller tasks in today's operational environment. Another source of information was NASA's Aviation Safety Reporting System (ASRS). A sample of near mid-air collision (NMACs) reports and other incident reports, filed during January 1, 1986 to December 31, 1987, was also reviewed to assess the kinds of operational errors that result from controller memory lapses.

There are two products of the controller memory literature review. The first is a definition of tactical working memory. The second is a controller cognitive model, which serves a conceptual framework for analyzing controller memory lapses and limitations, and for identifying potential memory aids.

2.2 Step 2: Identify Memory Problem Areas

A list of potential memory problem areas was developed from the memory literature review summary sheets. These problems were then analyzed by the technical team, which included an Air Traffic Control Specialist (ATCS). The ATCS served as the in-house subject matter expert (SME). The analysis of the problem areas involved two major tasks:

(1) Develop a list of controller operational problem areas in relation to specific controller tasks, using the FAA's operational error reports, ASRS reports, the MITRE Report (Kinney, Spahn and Amato, 1977) and controller task analysis;

(2) Determine the specific memory lapses related to each type of operational error.

The analysis of memory in relation to FAA operational error reports is ongoing. Some of the results will be included in this report, but the majority of the analysis and conclusions drawn from the FAA operational error data will be provided under a separate cover in the near future.

2.3 Step 3: Identify Potential Memory Aids

This phase of the effort involved determining appropriate job aids that reduce or eliminate identified memory lapses and related operational errors. Literature on job aiding approaches in general, and job aids specific to air traffic control was reviewed. A limited inquiry of active air traffic controllers was conducted to identify job aids being used. The result of the job aiding literature review was a list of techniques, approaches, and concerns pertaining to the development of controller memory aids.

Many of the job aiding approaches were gleaned from the literature. However, some of the proposed memory aids are based on informal procedures and "memory joggers" that controllers/facilities use today.

2.4 Step 4: Evaluate Potential Memory Aids

Criteria for evaluating potential aids were developed. These criteria were based on the nature and purpose of this project, and were discussed and agreed upon in conversations between contractor personnel and the COTR. These criteria and their definitions are presented in Table 2:

TABLE 2. EVALUATION CRITERIA AND THEIR DEFINITIONS

EVALUATION CRITERIA	DEFINITION
FACE VALIDITY	(a) Will *inexperienced* controllers accept and use the aid. (b) Will *experienced* controllers accept and use the aid.
USABILITY	How much training is required to effectively use the aid.
FEASIBILITY	Given existing hardware/software, how easily can the aid fit into current configuration.
EFFECTIVENESS	How effectively does the aid address memory limitations and associated system errors.
COST	What is the relative cost of purchase, installation and training.
TESTABILITY	How "testable" is the aid for Year 2 experiments of this project.

A list of potential job aids was prepared and evaluated using the subjective criteria. Based on these criteria, the highest-ranking aids are proposed for empirical testing in the second year effort.

The next section of this report presents the results of the controller memory literature review, including the definition of tactical working memory and the controller cognitive model. The analysis of controller operational errors and tasks, discussion of job aids, and the proposed memory aids will be presented in subsequent sections.

SECTION 3.0 THEORIES AND RESEARCH ON WORKING MEMORY

3.1 The Concept of Working Memory

Human memory is thought to be composed of three subsystems: sensory storage, working memory, and long term memory (Sanders & McCormick, 1987; Wickens, 1987; Wickens, 1984). Visual, auditory, and other sensory inputs are temporarily held in sensory storage for a few seconds or less. If attention is not directed to sensory storage contents, the contents will be lost. Directing attention towards sensory input will transfer it into working memory. Information in working memory is "temporary, fragile, and limited." (Wickens, 1987, p. 81). Working memory is limited by time, attention, space, and characteristics of the information itself (e.g., similarity between objects). Since it mirrors the three to five minute tactical window generally used by controllers, working memory is the primary focus of this effort.

Information is transferred from working memory to long-term memory (LTM) by semantic coding, or applying *meaning* to the information and relating it to what is already in LTM (Sanders & McCormick, 1987). LTM is of interest in this project to the extent that it helps or hinders the development of strategies for information search, storage, and retrieval.

In the absence of attention devoted to rehearsal, little information is retained in working memory beyond 10 to 15 seconds (Peterson & Peterson, 1959; Wickens, 1984). For example, Loftus (1979) asked subjects to remember navigational information (without rehearsal), such as that given to a pilot by an air traffic controller. He found that most information decayed after 15 seconds. Moray and Richards (1980, cited by Wickens, 1984) found a similar decay trend for radar controllers attempting to recall displayed information on a radar scope.

The number of unrelated items that working memory can hold, even with rehearsal, is limited. The capacity of working memory is "the magical number seven plus or minus two." (Miller, 1956). However, individual items can be "chunked" into familiar units, regardless of size, and these can be recalled as an entity. For example, IBMJFKTV is more difficult to recall than IBM JFK TV (Sanders & McCormick, 1987). Indeed, when Loftus (1979) examined subjects' ability to recall air traffic control information, he found that four-digit codes were better retained when parsed into two-digit chunks ("seventeen eighty-five") than when presented as four digits ("one seven eight five").

The number of attributes of a single object that must be remembered affect its ability to be chunked (Wickens, 1987). For example, Yntema (1963, cited in Wickens, 1987) found that subjects showed much better memory for a small number of objects that varied on a greater number of attributes than for many objects that varied on few attributes. The implication for air traffic control is that altitude, airspeed, heading, and size of two aircraft would be better retained than the altitude and airspeed of four aircraft, even though in each case eight items are to be held in working memory (Wickens, 1987).

What causes people to forget items in working memory? Two major causes seem to contribute to the disruption of the memory trace: (1) the memory "decays" and becomes less meaningful as time passes, (2) a competing activity disrupts the trace through *interference* (Wickens, 1984). Interference can result from similarity, retroactive inhibition, or proactive inhibition. When a group of items to be remembered are very similar , more forgetting occurs (Wickens, 1987). For example, Fowler (1980) discussed the problem of similar fleet numbers among aircraft. The interference due to similarity between items makes it difficult for the controller to maintain their separate identities (i.e., by time of arrival) in working memory (Fowler, 1980).

Retroactive inhibition is interference due to any activity that takes place between the time that the material is encoded into memory and the time that it is retrieved for later use (Wickens, 1984). The retention and retrieval of Task B information, for example, may be inhibited by performing a Task C which follows and which intervenes between the learning and retrieval of Task B information. Likewise, Task A which precedes Task B may interfere with retention of Task B material. The latter is referred to as proactive inhibition. A manifestation of proactive interference was observed by Loftus (1979) in the study of air traffic control communications. He found that recall on a given trial was significantly disrupted if it followed the preceding trial by less than 10 seconds. Intervals of greater length apparently allowed the material from the preceding trial to dissipate, so that its subsequent interference with new material would be minimized.

The above discussion describes human limitations of search and retrieval from working memory. However, capabilities and limitations of information *storage* should also be considered. Directing *attention* towards stimuli is required for information to be processed from sensory storage into working memory. Wickens (1984) discussed the searchlight metaphor to describe this perceptual type of attention: "Momentary direction of attention can be thought of as a searchlight. . . Everything within the beam of light is processed whether wanted (successful focusing) or unwanted (failure to focus)" (p. 250). There are three different types of situations, or tasks, which determine how this "beam" of attention is focused (Sanders & McCormick, 1987). In the first, *selective attention*, a person monitors several sources of information to determine whether a particular event has occurred. For example, a controller scans information on the radar scope to determine if a particular aircraft has "acquired". In the second type of task, *focused attention*, a person attends to one source of information and excludes all others. For example, a controller listens to a pilot's clearance request on the radio and shuts out all other noise. Finally, in a *divided attention* situation, the person must perform two or more tasks simultaneously, which requires *time-sharing* of attention between the tasks. For example, the controller utters clearance delivery information while simultaneously marking the flight strip.

In the last type of attention task, a broader range of human performance must be considered than merely perception. Wickens (1984) describes this broader range in terms of *resources*, in which a limited amount of mental processing can be directed toward two or more simultaneous tasks. Wickens' multiple resource theory postulates several independent resource pools, and states that when tasks share the same resource pools, performance will be disrupted. While much theory building and research has been accomplished using this model in recent years, predictions on the outcome of time-sharing real-world tasks, such as in air traffic control, are still somewhat premature (Sanders & McCormick, 1987).

3.2 Review of Air Traffic Controller Memory Research

The functioning and organization of working memory in air traffic controllers has been experimentally investigated by few researchers. These studies are briefly described below. Implications of the results for controller working memory are also discussed.

Leplat and Bisseret (1966) developed a working model of controller mental processes in which they propose that the primary mental task of controllers is a *categorization* task. Aircraft are defined by attributes and their specific values. Attributes that a controller uses depend on his goal, which is to maintain separation between aircraft. The controller is not concerned with individual aircraft, but pairs of aircraft, specifically, *future states* of aircraft pairs. The future states are classified into two main categories: conflicting pairs and others. Leplat and Bisseret analyzed verbal protocols (think aloud technique) and interviews to determine the organization and functioning of controller mental processes. They found that the following six attributes of aircraft pairs are compared in this order:

1) Level
2) Flight paths
3) Longitudinal separation
4) Relative speeds
5) Direction of flights after reporting points
6) Lateral separation.

After comparison of data at each attribute, the controller determines conflict or no conflict If there is no conflict, he takes no further action. If there is conflict, he issues control instructions and continues monitoring the situation.

In a later study, Bisseret (1971) used this model to examine the effects of controller qualification level and amount of traffic on what he called the controllers' 'operative memory" (p. 567). Controller qualification levels were trainee, controller, and first controller. Traffic levels were 5 aircraft, 8, aircraft, and 11 aircraft. Operative memory was measured by the following dependent variables:

(1) Number of aircraft recalled

(2) For each aircraft, number and type of attributes remembered

(3) Errors in the values of the attributes.

Bisseret hypothesized that the *reasoning processes* controllers use (i.e., categorization) affect functioning of operative memory (but he did not specify how this functioning would be effected). In the experiment, controller subjects were presented with a series of flight strips and told to analyze the traffic situation. They were told that the experiment was concerned with problem-solving time, so they did not know it was actually their memory being tested. At a given time, not anticipated by the subject, the experimenter removed the strip board and asked the subject to recall all he knew about the traffic situation. Bisseret found that the *number of aircraft recalled increases with increases in controller experience* and *decreases with the increases in traffic* presented in the problem. Neither qualification level nor traffic level had any effect on number of attributes used to remember an aircraft. Controllers remembered an average of *three attributes*. Which attributes were recalled depended on the traffic situation. However, *level* and *relative position*, which correspond to the first two attributes controllers consider according to Leplat & Bisseret's model (1966), were better memorized and used more frequently. A qualitative analysis of attribute errors revealed "not really errors, but rather lack of precision or alteration of reality" (p. 569). Bisseret found that most errors placed the aircraft forward of their real positions. He concluded that all of these results provided evidence that "memorization is adapted to the mental processes that deal with *future state*" (p. 569).

The results obtained by Leplat and Bisseret (1966) and Bisseret (1971) suggest, first of all, *ability to memorize traffic data increases with experience*, and secondly, that *amount of traffic affects memory*. The latter result is consistent with Miller's (1956) findings on working memory, specifically, that capacity is *7 ± 2 chunks*. The first result implies that controllers develop more efficient chunking strategies with experience, thus enabling them to recall more information about a traffic situation. The implication for memory aids is that information should be presented in such a manner so that it is easily chunked. Important pieces of information should be highlighted and made easily accessible.

A colleague of Leplat and Bisseret, Sperandio (1971) examined the effects of workload on controller *cognitive strategies*. Sperandio proposed that increasing workload does not necessarily impair performance, rather, workload affects operational strategies which enable controllers to maintain a chosen level of performance. By varying their strategies within the flexibility allowed by the task, controllers can maintain their workload at a level compatible with information processing limits.

Sperandio tested this idea by presenting 15 approach controllers with varying levels of traffic on a simulated radar display. The display included a video map and distance markers with aircraft and corresponding call signs. The number of aircraft on each display varied from 4 to 8 (five levels), and the number of aircraft already under control (already given landing instructions) was either zero, two or four (three levels). Controllers were instructed to sequence the "non-controlled" aircraft for landing and give control instructions accordingly. To do so, they had to request data such as headings, flight levels, speeds, aircraft types, etc. The experimenters collected the following information: (1) routing solutions chosen (direct approaches, standardized routings, use of holding patterns, and separation distances between aircraft), and (2) the data requested by each controller and the order of this data.

Sperandio found that, under low traffic levels, controllers used more *direct routings*. At higher traffic levels, they tended to use *standardized routings* and more holding patterns. Secondly, when traffic increased from four to eight aircraft, the number of data relative to performance (aircraft type, size, speed, rate of descent, etc.) increased from 4 to 6, then decreased from 6 to 8. When routing was direct, performance data were requested for 85% of the aircraft. When routing was standard, performance data were requested for only 30%. Based on this evidence, Sperandio suggested the following model: when traffic was low, the controller used more direct routing strategies which required him to know more performance data necessary to separate the aircraft. When traffic was high, the controller immediately used standard approaches which did not require knowledge of performance data except to give more precise instructions. Thus, when traffic level increased, the controller reduced the number of variables he must process. Controllers seemed to *"self-regulate"* their operating strategies. They used more economical methods when traffic load reached their capacity limits and less economical methods when traffic load did not stress their limits. Sperandio suggested that, with low workloads, the less economical method also fulfilled the controllers' need to maintain activity. He concluded that *automated aids must be flexible enough to follow the controller's strategies.*

The implications of Sperandio's and Bisseret's work for the organization of tactical working memory and for the design of memory aids are clear. First, information in working memory is probably organized *hierarchically*. The more important a piece of information, the more frequently it is likely to be used (for example, flight level) and accessible. This idea is consistent with Bisseret's conclusion that working memory is "a temporary memory of real data, organized and structured by the processes of work" (cited by Sperandio, 1978, p. 198). It contains information both useful (always retained in memory) and useless (only retained within the limits of "available space"). Secondly, job aids should be designed to be *flexible* enough to vary with controller strategies. For example, the controller may sometimes need additional information for each aircraft, but this information should not always be presented because it would clutter the scope and the controller's mind under high traffic loads. Under low traffic loads, the controller should be able to easily select an option to display the additional data.

3.3 A Definition of Controller Tactical Working Memory

We have developed a definition of controller tactical working memory based on general knowledge of memory functions and organization. Our definition includes general characteristics of controller tactical working memory, in terms of functional requirements, contents, capacity, limitations and organization. The functional requirements are:

1. *Attention* is required for sensory input to be processed into working memory.

2. *Rehearsal* is required to maintain the contents of working memory for the three to five minute tactical window.

The *contents* of controller working memory in tactical operations include data such as:

- Current altitude, airspeed, heading, size and type for each controlled aircraft
- Projected altitude, airspeed and heading based on planned tactical maneuvers (clearances to be given)
- Recent communications such as change in route of flight/altitude, clearance requests, etc.
- Weather conditions; runway conditions, navigational aids status
- Each aircraft's position under his control in the controlled airspace, and in relation to other air traffic
- Projected potential conflictions between aircraft based on the above information.

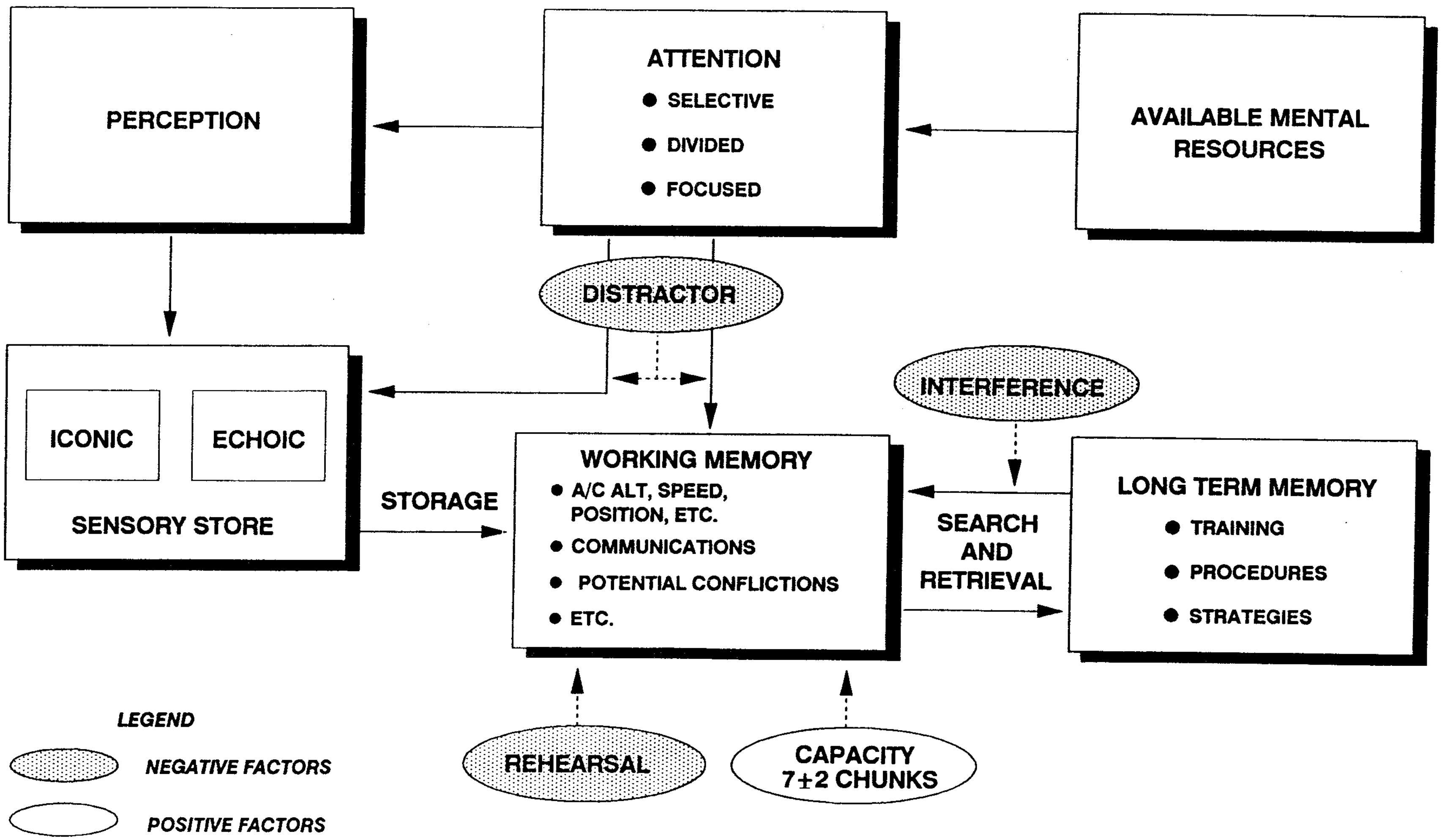
The above items are probably chunked in some fashion because the number of individual items exceeds 7 $\pm$ 2. The number of individual items in working memory will also vary by the number of aircraft in a controller's airspace, which probably affects chunking strategies within memory, as well as operational strategies that determine memory organization. As demonstrated by Sperandio's (1971, 1978) and Leplat and Bisseret's (1966, 1971) work, traffic loads and situations affect decision processes, and decision processes affect both the sequence of mental operations and the number and kinds of data used in those operations. Thus, working memory is organized hierarchically, with the most important information at the top (e.g., conflict or no conflict between two aircraft) and less important information below (e.g., type or speed of each aircraft). Information is also organized to *project* future states.

The contents of tactical working memory are constantly changing. Existing information is updated, new data is added, and old information is thrown away. There is a great potential for interference due to similarity between items, proactive and retroactive inhibition. The demand on the controller's attentional resources to update working memory contents, in response to the dynamic environment, is quite high.

The contents of *long term memory* affect storage, search and retrieval of information from tactical working memory. The controller's training, procedures in use, and preferred control strategies will affect storage, search, and retrieval functioning.

Thus, our definition of controller tactical working memory consists of functional requirements (attention and rehearsal), contents (aircraft data, position, etc.) capacity (7 ± 2), and limitations (interference) within a three to five minute tactical window (Figure 2). The organization of information within tactical working memory depends heavily on individual differences and situational factors, such as traffic load. The controller's training, procedures in use, and personal preferences, all of which reside in long term memory, determine specific search and retrieval mechanisms. However, the main objective of this effort is to develop a sufficient understanding of working memory in relation to controller tasks, and to determine memory lapses that lead to controller operational errors. It is toward this objective that the remainder of the report is focused.

FIGURE 2. WORKING MEMORY



SECTION 4.0 CONTROLLER COGNITIVE MODEL

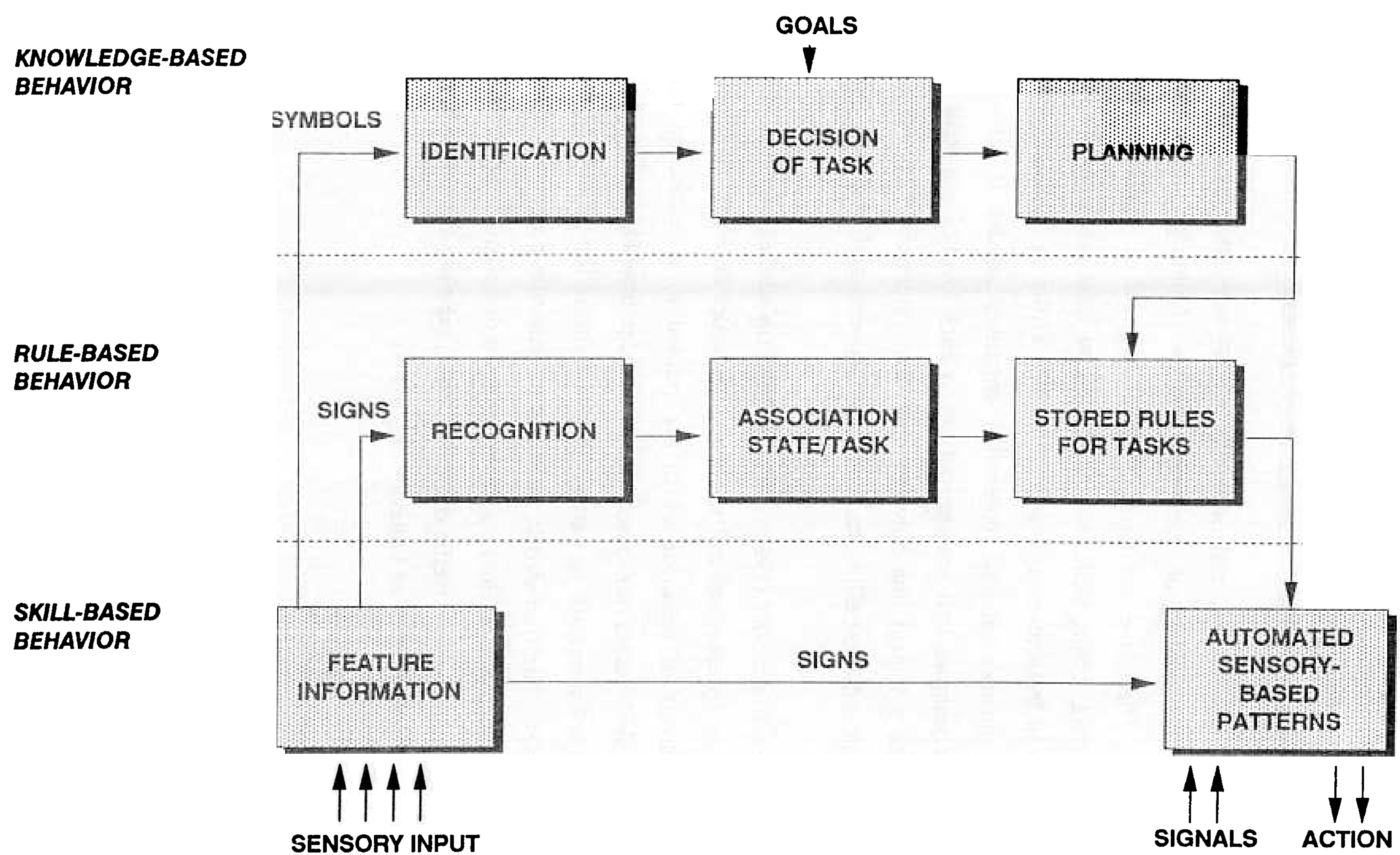
A true appreciation and understanding of how controller memory lapses occur, requires an understanding of controller cognitive functioning over the whole range of performance. Therefore, we have adapted a model of cognitive control of behavior (Rasmussen, 1982, 1986), which we have used to help categorize controller operational errors that result from memory lapses and relate errors to the appropriate cognitive level. The second purpose of the controller cognitive model is to classify job aiding approaches/techniques that are appropriate to each level of cognitive control. Thus, the model provides a logical link between controller operational errors/memory lapses and appropriate job aids that allow controllers to prevent, and/or detect and correct memory lapses.

Rasmussen's model (1982, 1986) is based on studies of event reports and operator performance on complex control rooms. The model describes cognitive control of three hierarchical levels of behavior which are related to a decreasing familiarity with the environment: skill-based, rule-based, and knowledge-based behavior (Figure 3). The model also provides a framework to categorize the information-processing mechanisms behind error categories. The framework, including information-processing mechanisms and error categories as originally defined by Rasmussen are described below. Using this framework, we have also identified air traffic controller tasks, memory components, and memory errors associated with each level of behavior (Figure 4).

4.1 Skill-based Behavior

Skill-based performance is the most basic. It refers to the perception and almost automatic response to signals, data, and physical elements of the work environment. Skill-based behaviors represent over-learned activities, largely manual, and do not require much cognitive control. Behavior is governed by "sensorimotor schema" which provide information about specific action sequences. Once a schema is activated, it continues almost

FIGURE 3. COGNITIVE CONTROL DOMAINS*



FROM RASMUSSEN, 1982

FIGURE 4. MEMORY ELEMENTS OF ATC COGNITIVE CONTROL

PERFORMANCE

KNOWLEDGE-BASED

- UNFAMILIAR ENVIRONMENT
- GOAL-CONTROLLED PERFORMANCE BASED ON MENTAL MODELS
- FORM STRATEGIES, MAKE PLANS

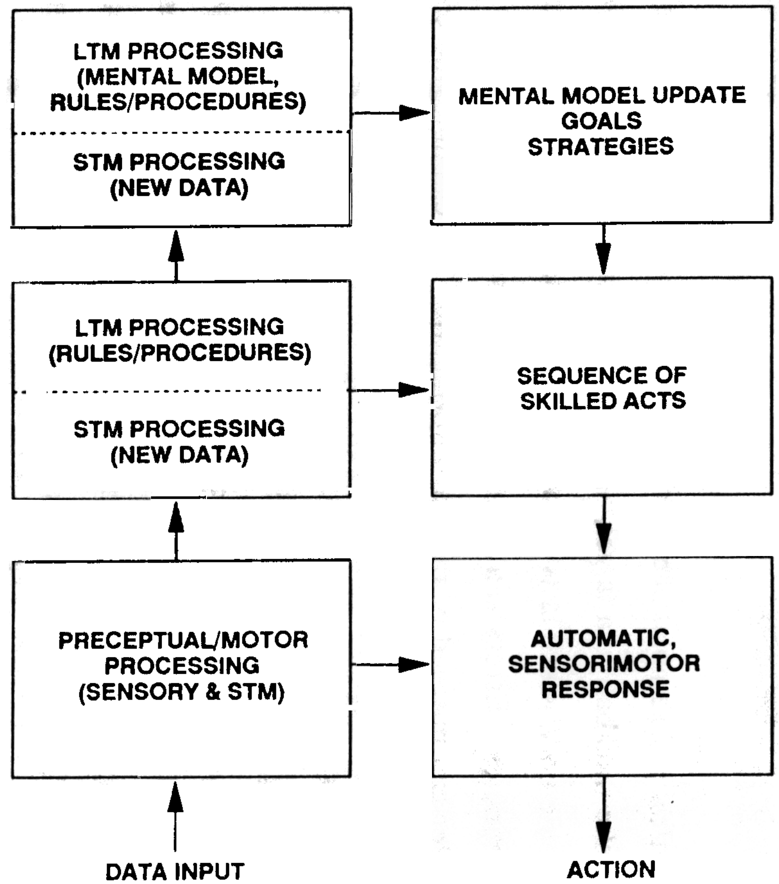
RULE-BASED

- FAMILIAR ENVIRONMENT
- BASED ON STORED RULES/PROCEDURES FROM INSTRUCTION OR EXPERIENCE
- COORDINATE & CONTROL SKILLED ACTION

SKILL-BASED

- FAMILIAR ENVIRONMENT
- HIGHLY AUTOMATED SENSORIMOTOR PERFORMANCE
- MOVE BODY THROUGH ENVIRONMENT & MANIPULATE OBJECTS

MEMORY



automatically. Examples of controller skill-based performance include radar scope scanning, rolling the trackball to a target, and marking flight strips. At this level, the controller uses sensory memory, which lasts a few fractions of a second, and short term memory which lasts a few minutes. Errors can occur at any processing stage. At the perceptual stage, the controller can misread or mishear information. For example, the controller mishears the aircraft call sign because there is noise or static on the line. This is often a problem when the ATCS is controlling two aircraft with similar call signs, and he confuses one for the other during communications (Monan, 1983).

A second group of skill-based errors involve the motor component, and can result from normal human variability in performance. For example, the controller pushes button B instead of button A. Rasmussen (1986) calls this group of errors "man-system mismatches", specific types of which include motor variability, topographic misorientation, and stereotype takeover. *Motor variability* results from a lack of precision in the motor movement. *Topographic misorientation* occurs when the person misjudges the physical environment. *Stereotype takeover* occurs when another motor schema takes control because the person's attention from the original schema was diverted. The main point here is that skill-based errors due to human variability will occur, therefore, systems should be made error tolerant. The implication for design of job aids is that they should be compatible with the existing design of work stations and tasks, and should also be tolerant to variability in skill-based performance.

A third type of error that can occur does involve cognitive processing and memory, specifically, the encoding and rehearsal of data in working memory. If the controller is *distracted* or his attentional resources are overly taxed during this processing, the data is lost from working memory. Examples include not taking notes properly and forgetting what was supposed to be written down, and not completing one transaction before going on to another.

4.2 Rule-based Behavior

Rule-based performance is at a higher cognitive level and consists of use of procedures and rules. The controller recognizes a situation and associates it with a stored rule or procedure for executing the tasks. Rules and procedures come from either instruction or experience and are maintained in long term memory (LTM). Working memory is used to process the new, incoming data. Any interference or distraction during this processing can result in forgetting, or errors in recall. Rasmussen (1986) identified several error types for this performance level that result from human variability. They include *forgetting an isolated item* (e.g., a frequency), *omission of an isolated act* (forgetting to inform another controller of something), *incorrect recall of isolated items* (transposing numbers, confusing similar call signs), and *mistake among alternatives* (choosing the wrong procedure to enact for a situation).

A second group of error types result from improper human adaptation to system/environment changes. In these cases, changes in the environment require the operator or controller to shift to a higher level of behavioral control, but for some reason, he or she does not. Rasmussen (1986) calls this failure to activate knowledge-based control *"familiar association short-cut"* (p. 58). Changes in the system that require rational reasoning (i.e., knowledge-based reasoning) are not perceived by the operator. Instead, the operator relies on familiar signs that do not normally require analytical interpretation. Rasmussen (1986) asserts that there is a considerable probability that this type of error occurs with highly skilled (i.e., experienced) operators who have a large repertoire of convenient signs and procedural short-cuts.

4.3 Knowledge-based Behavior

Knowledge-based performance is the highest level of behavioral control. It involves the formation and maintenance of an individual's mental model of the operational situation. This level is especially critical for dealing with novel situations. At the knowledge-based level, the controller must analyze the environment, form a goal, and develop a plan or strategy. His analysis of the situation depends upon his internal representation of the system he is controlling -- his mental model or "picture" of the system. An example of knowledge-based performance is that of a controller just coming on to position. He must analyze the traffic situation, form goals in terms of keeping specific aircraft separated, and develop a strategy (e.g., vectoring, speed/altitude changes, etc.) for doing so. If the controller has not been briefed properly by the previous controller at the position, or if he has *forgotten* what he had been told, his mental model, goals, and strategies may not be appropriate for the traffic situation. Obviously, both working and long term memory are involved in knowledge-based performance. Processing or memory errors that occur at the lower levels of skill- and rule-based performance will ultimately affect processing at the highest level. Similarly, the controller's goals and strategies for dealing with a situation will affect the procedures and rules he enacts to carry out tasks, as well as the tasks themselves.

Errors that occur during knowledge-based reasoning result from improper or inadequate adaptation to system changes. Rasmussen (1986) classified these mismatches into two groups:

1. Adaptation to system/environment changes is outside the person's capability limits -- knowledge is not available due to excessive time or workload requirements.

2. Adaptation is possible, but unsuccessful due to incorrect decisions which result in acts upon the system that are inappropriate.

An example of the first type occurs when the controller loses the "picture" because of excessive workload or stress. An example of the second type of error is provided by an accident that was originally described by Danaher (1980). An L-1011 wide body jet was diverted from its night approach to Miami International Airport because of an apparent malfunction in the nose landing gear system. The pilot followed an ATC clearance to proceed west from the airport at 2000 ft altitude, at which time he engaged the autopilot to reduce workload so they could determine the cause of the malfunction. Preoccupied with this malfunction, the crew did not notice a gradual descent resulting from inadvertent disengagement of the autopilot. At one point during the diversion, the Miami approach controller noted an altitude reading of 900 ft in the flight's data block on the radar scope, and inquired, "How are things comin' along out there?" (Danaher, 1980, p. 542). the flightcrew responded with an indication of satisfactory progress and intent to return to the airport. This response, plus the knowledge that the ARTS-III equipment could indicate incorrect information for up to three scans, led the controller to believe that the flight was in no danger. Less than 30 sec after this last exchange, the aircraft struck the ground, killing 99 of the 163 people aboard. A different outcome may have occurred if the controller had been prompted to advise the flight of its *altitude* based on his displayed altitude indication. Instead, he apparently made an *inappropriate decision* which went undetected at the time.

The various error types discussed above are summarized in Table 3. These error categories will be used to analyze and describe controller operational errors, and are discussed in Section 5.0.

TABLE 3. SUMMARY OF COGNITIVE ERROR CATEGORIES[1]

ERRORS DUE TO HUMAN VARIABILITY	
SKILL	o MOTOR VARIABILITY o TOPOGRAPHIC MISORIENTATION o STEREOTYPE TAKEOVER o DISTRACTION
RULE	o INCORRECT RECALL OF RULES AND KNOW-HOW o FORGETTING AN ISOLATED ITEM o OMISSION OF AN ISOLATED ACT o INCORRECT RECALL OF ISOLATED ITEMS o MISTAKE AMONG ALTERNATIVES
ERRORS DUE TO IMPROPER HUMAN ADAPTATION TO SYSTEM CHANGES	
SKILL	o STEREOTYPE FIXATION o STEREOTYPE TAKEOVER
RULE	o FAMILIAR ASSOCIATION SHORT-CUT
KNOWLEDGE	o ADAPTATION TO CHANGES OUTSIDE CAPABILITY LIMITS o ADAPTATION POSSIBLE, BUT UNSUCCESSFUL DUE TO INCORRECT DECISIONS/ACTS

[1]Rasmussen, 1986

SECTION 5.0 CONTROLLER MEMORY AND OPERATIONAL ERRORS

A number of factors are at work in the efficient control of aircraft: the air crew, controllers, airline personnel, prevailing conditions, and the operational status of the aircraft. An operational error usually involves some combination/interaction of the above factors. To monitor and evaluate such errors, the FAA has instituted the National Airspace Incident Monitoring System (NAIMS) which provides data on operational errors and deviations, near midair collisions, and pilot deviations. The Operational Error System (OES) is a component of NAIMS that provides data on preliminary and Final Operational Error and Operational Deviation Reports (Forms 7210-2 and 7210-3) submitted to the Office of Aviation Safety from air traffic field facilities throughout the nation. Operational errors are "violations of the applicable minimum separation criteria between two or more aircraft, or between aircraft and terrain, obstacles, or obstructions" (FAA, 1987, p.1).

In 1986, 1352 operational errors were reported to the FAA and recorded in the OES database. About 96% of these errors were attributed to *human error*, as opposed to equipment malfunction, etc. (FAA, 1987). The impact of human error was also noted about ten years earlier, in an analysis of controller and supervisor performance to identify factors underlying system errors. Kinney, Spahn & Amato (1977) analyzed the existing database (the System Effectiveness Information System), and reported that more than 90% of the errors were attributed to failures in *attention, judgement, and communication*. Kinney, Spahn and Amato also visited several air traffic control facilities and observed controller performance to determine the elements and underlying causes of system errors. System error elements were defined as "those control techniques or work habits which contribute to, lead to, or directly bring about a system error" (p. 4-1). The most frequently observed system error elements (not in any order of importance) included:

1) controlling in another controller's airspace
2) timing and completeness of flight data handling
3) inter-positional coordination of data
4) use of altitude (Mode C readout) on display

5) procedures for scanning and observing flight data and displays
6) phraseology and use of voice communication
7) use of human memory, especially in avoiding mental blocks
8) dependence on automatic capabilities.

We adapted Kinney, Spahn and Amato's system error element categories in our analysis of near mid-air collision reports (NMACs) filed with NASA's Aviation Safety Reporting System (ASRS) (Table 4). The purpose of this review was to determine how controller work habits and techniques, as categorized by Kinney et al., contributed to memory failure and resulted in the NMAC. A sample of 69 ASRS reports, filed between January 1, 1986 to December 31, 1987 was analyzed. The analysis was accomplished more to gain *insight* into the nature of memory-related errors than to determine statistically valid frequencies of occurrence. (ASRS reports are submitted voluntarily, thus they cannot be used for statistical purposes because the underlying population is unknown. However, the FAA's OES database can be used to determine frequencies of operational error occurrence. An analysis of these reports (FAA, 1987, 1988) is ongoing and will be submitted under a separate cover.) By understanding the nature of controller work habits and techniques that contribute to memory lapses, we can then identify job aids (new devices and/or procedures) that provide controllers with structured procedures that enable them to prevent errors from occurring.

Each ASRS report in the sample was reviewed and placed into one of the system error categories. Based on the information provided in the ASRS narratives, a scenario was developed that described a "typical" sequence of events and controller actions that lead to the system error category. For each system error category, a list of potential underlying causes was generated. For example, the underlying causes that result in controlling aircraft in another's airspace include lack of proper coordination, utilizing ARTS readout and not verbal communication, and shortcutting or attempting to expedite aircraft movement. Any of these causative factors could have been the true source of the error.

TABLE 4. OPERATIONAL ERROR CATEGORIES AND CAUSATIVE FACTORS

1. CONTROLLING AIRCRAFT IN ANOTHER'S AIRSPACE

a. Lack of proper coordination.
b. Utilizing ARTS readout and not verbal communication.
c. Shortcutting or attempting to expedite aircraft movement (pilot intimidation.)

2. PROCESSING FLIGHT DATA MANUALLY INTER/INTRA-FACILITY

a. Delay in processing information that will eventually be shared by other controllers.
b. Failure to upgrade computer entries and associated manual strip updating.
c. Improper processing or sequencing of active data (e.g. departure/arrival sequences) which confuses other controllers sharing data.
d. Not manually noting pertinent information but relying on recall memory.
e. Poor housekeeping.

3. INTER/INTRA-FACILITY COORDINATION

a. Inappropriate use of intercom.
b. Assuming message has been received when there is no verbal acknowledgement.
c. Issuing clearance into another sector's airspace before receiving verbal permission.
d. Failure to verify message information.

4. ASSUMING SEPARATION WILL EXIST.

a. Climbing or descending one aircraft when not in control of other aircraft.
b. Using Mode C altitude of aircraft not under control as barometer for issuing clearance.
c. Assuming information presented is factual.
d. Lack of positive control.
e. Not issuing traffic information in a timely manner.

5. IMPROPER RADAR/VISUAL SCANNING.

a. Inattention or lack of discipline in updating/scanning radar displays for potential conflictions.
b. Inattention or lack of discipline in updating/scanning traffic patterns for potential conflictions.
c. Focusing attention in one quadrant of radar scope or traffic pattern when events dictate complete scanning.
d. Inappropriate mental checklists while scanning radar displays/traffic patterns, thus failing to understand what is seen.

6. INAPPROPRIATE PHRASEOLOGY AND IMPROPER VOICE COMMUNICATIONS.

a. Nonstandard phonetics and numbers.
b. Improper usage of control instructions.
c. Homespun phraseology.
d. Poor intercom procedures.
e. Levity, non-ATC-related conversations.
f. Cut off transmissions.
g. Failure to control frequency.
h. Inattentiveness to readbacks.

7. OVERUSE OF AUTOMATION (NAS DEPENDENCE).

a. Non-verification of essential information.
b. Failure to assign proper priority to the exchanging of essential traffic information.
c. Lack of symbology indicating non-existence of aircraft.
d. Relying on the automated system to provide control solutions.
e. Invalidation of Mode C readout.
f. Lack of stripmarking to assist in the event of system failure.
g. Using information or lack of information as a causative factor when explaining "what happened."

System error categories and their descriptive scenarios were also related to the cognitive error categories identified by Rasmussen (1986) that were discussed in Section 4.0. We determined the underlying cognitive processes that result in various types of error and related them to the controller cognitive model. In this way, we could identify the memory component(s) that contributed to the error and potential memory aids. The memory factor(s) associated with each system error category are discussed in terms of our concept of controller tactical working memory (Section 3.0). For some error categories, we provided supplemental information that is not directly related to memory, but contributes to an understanding of the sources of error and potential ways of eliminating them. Table 5 provides a summary of operational error categories, cognitive errors, and memory factors that are discussed in detail below.

TABLE 5. OPERATIONAL ERRORS, COGNITIVE ERRORS AND MEMORY

OPERATIONAL ERROR	COGNITIVE LEVEL	COGNITIVE ERROR	MEMORY FACTOR
Controlling aircraft in another's airspace	Rule-based	Omission of an isolated act	Use of procedural shortcuts under low traffic leads
Manual processing of flight data	Rule-based	Incorrect recall of isolated items Forgetting an isolated item	Reliance on recall rather than recognition of data
Inter/intra-facility coordination	Rule-based	Omission of an isolated act	Distraction from task by non-work-related conversation
Assuming separation will exist	Rule-based	Familiar association short cut	Training and experience, a "hot rod" attitude
Improper radar/visual scanning	Knowledge-based	Adaptation unsuccessful due to incorrect decision	Focusing attention on one task rather than dividing attention among 2 or more tasks
Inappropriate phraseology/ voice communication	Skill-based	Stereotype takeover	Controller expectation combined with misuse of microphone
Overuse of automation	Skill-based	Stereotype takeover	Controller expectation

5.1 Controlling Aircraft in Another's Airspace

Scenario: Controller A, at pilot request, clears a departure aircraft directly to a departure fix, turning the aircraft inside of the 10 mile mandatory turning area. He then climbs the aircraft to assigned altitude without coordinating with Controller B for usage of his airspace. The result is lack of standard separation between his aircraft and one of Controller B's aircraft. Controller A's rationale is that he "quick-looked" (alphanumeric key entry that allows controller to observe on the radar scope aircraft not under his control) Controller B's aircraft and didn't see any traffic.

Causative Factors: Improper coordination procedures, i.e., use of ARTS readout for required information rather than verbal communication; short-cutting or attempting to expedite aircraft movement.

Relationship to Controller Cognitive Model: This type of operational error corresponds to the cognitive error *omission of an isolated act* associated with rule-based behavior. By attempting to expedite the situation, the controller forgot (or did not want) to inform the other controller of what he was doing.

Memory Factor: Under low traffic loads, controllers tend to use procedural shortcuts in order to expedite traffic movement. Standardized procedures are learned in training, and generally followed under high traffic load situations, but not always under low traffic loads. A memory aid that fosters use of proper procedures (via reminders or checklists, for example) would eliminate this type of operational error.

5.2 Processing Flight Data Manually Inter/Intra-facility

Scenario: Radar approach controllers relay the landing sequence, including types of aircraft, to the tower Assistant Local Controller (ALC). This information is placed on flight strips in front of the Local Controller (LC). Due to a changing traffic picture, approach control then revises information including type of aircraft and position in the landing sequence, so that movement of strips and written revisions are required. ALC should tell LC of changes immediately (both written and verbally), but waits and forgets some of the information which leads to a runway incursion.

Causative Factors: Delay in processing information that will be shared by other controllers; failure to upgrade computer entries and associated manual strip updating; improper processing or sequencing of active data; not manually noting pertinent information but reliance on recall memory; poor housekeeping.

Relationship to Controller Cognitive Model: This type of operational error is related to the cognitive errors *incorrect recall of isolated items* and *forgetting an isolated item* associated with rule-based performance. By not using appropriate note-taking procedures, the controller forces himself to rely on recall, which is highly susceptible to interference, rather than recognition.

Memory Factor: As mentioned above, reliance on recall rather than recognition places a higher load on memory and attentional processes. Kinney et al. (1977) observed that poor note-taking and organization of flight strip data (what they called "poor housekeeping") was a major source of operational errors. Frequently observed controller note-taking actions that did not facilitate memory included (a) not taking notes when there was an opportunity to do so, thus increasing reliance on recall, (b) not taking notes in such a way that the form and content were organized in accordance with what had to be remembered, (c) not canceling old items on notes and strips, which caused confusion as to which items were current or active, (d) not adopting a fixed scheme or method for use at all times, (e) not writing large enough or legibly enough, thus failing to aid memory effectively, and (f) not keeping notes in such a way as to aid passing relevant information to another controller when relieved at the position. A procedure or job aid that can enhance note-taking and use of flight strips will eliminate this source of operational errors.

5.3 Inter/Intra-Facility Coordination

Scenario: Controller A clears an aircraft to deviate away from adverse weather without coordinating with Controller B whose airspace will be penetrated by the deviating aircraft. Controller A has plenty of time to perform coordination but is distracted by non-work-related conversation on the intercom. Controller A then tries to hurry up and complete the coordination, but can't get through to Controller B who is extremely busy due to the adverse weather. He uses the intercom to request aircraft deviation but does not receive any verbal acknowledgement. Controller A assumes Controller B got the information, and turns his attention to other tasks. In the meantime, the deviating aircraft is not recognized by Controller B in enough time to prevent less than standard separation with another aircraft.

Causative Factors: Issuing clearance into another sector's airspace before receiving verbal permission; assuming message has been received when there is no verbal acknowledgement; failure to verify message information

Relationship to Controller Cognitive Model: This type of operational error is related to the cognitive error *omission of an isolated act* associated with rule-based behavior. By allowing himself to be distracted by non-work-related conversation, the controller did not remember to enact the correct procedure in enough time to prevent an incident.

Memory Factor: In low to moderate workload situations, controllers are more prone to distraction and socializing. In this scenario, Controller A did not *forget* to coordinate with the other controller, but *remembered too late*. As with operational error #1, a memory aid that ensures controllers use proper coordination procedures would eliminate this source of operational errors.

5.4 Assuming Separation Will Exist

Scenario: Controller A has several departure aircraft under his control, one of which he is radar vectoring to a center controller's airspace at 9,000 ft with a final altitude request of 11,000 ft. This aircraft will go between two arrival aircraft at 12,000 ft that are under control of Controller B. Controller B assumes the departure aircraft will stop climb at 9,000, which is the lateral limit of his airspace, and descends his arrival aircraft to 10,000 ft. well within his airspace. Controller A, using Mode C altitude readout on Controller B's aircraft, assumes the arrival aircraft are maintaining 12,000 ft. Controller A climbs his departure to 11,000 ft. without verbal coordination. Due to computer altitude readout lag, he fails to see the arrival aircraft descending. This results in a less than standard separation between the departure and arrival aircraft.

Causative Factors: Climbing or descending one aircraft when not in control of other aircraft; using Mode C altitude of aircraft not under control as barometer for issuing clearance; assuming information presented is factual; lack of positive control; not issuing traffic information in a timely manner.

Relationship to Controller Cognitive Model: This type of operational error is associated with a failure to activate knowledge-based control that results in *familiar association short-cut*. The controller did not perceive a change in the traffic situation that required him to shift to knowledge-based reasoning. Instead, he relied on familiar signs, i.e., Mode C readout. Assuming the arriving aircraft were actually at the displayed altitude, the controller went ahead and climbed his departing aircraft, leading to an error.

Memory Factor: Controller training and experience, reflected in long term memory, influences the occurrence of this kind of operational error. A controller can develop a habit of using inappropriate control procedures because they seem to lighten his workload. This is reflected in what Kinney et al. (1977) called the "hot rod attitude" seen in some controllers. A controller with a hot rod attitude thinks that his way of doing things is as good as or better than anyone else's, including recommended standards and required practices in FAA handbooks, etc. Mandated use of certain procedures, supplemented with directives to and support of supervision (i.e., detecting and dealing with the hot rod attitude) would eliminate this source of operational errors (Kinney et al., 1977).

5.5 Improper Radar/Visual Scanning

Scenario: Controller A has several aircraft spaced 10 miles apart descending from 17,000 to 10,000 for hand-off to approach control. Knowing that aircraft enter the back of Controller A's holding pattern airspace at 13,000 ft, Controller B requests permission to use 12,000 for a slow, light aircraft that will barely penetrate Controller A's airspace. Controller A, who is not holding, approves it. A moment later, approach control advises Controller A that holding is necessary. Controller A starts to establish a holding pattern, stacking his aircraft 1,000 ft apart from 10,000 to 14,000 ft. He becomes totally involved in obtaining vertical separation on his own aircraft, and doesn't see the aircraft at 12,000 ft in the back of his holding pattern. This results in two aircraft at 12,000 ft with less than standard separation.

Causative Factors: Inattention or lack of discipline in updating/scanning radar displays for potential conflictions; focusing attention in one quadrant of radar scope or traffic pattern when events dictate complete scanning; inappropriate mental checklists while scanning radar displays/traffic patterns, thus failing to understand what is seen.

Relationship to Cognitive Model: This type of operational error corresponds to one of the knowledge-based cognitive error concerning adaptation to system changes. In this case, *adaptation was possible, but unsuccessful due to incorrect decisions/acts*. By focusing entirely on controlling the holding pattern, the controller failed to take into consideration the light aircraft.

Memory Factor: In the scenario described above, the controller *focused his attention* on stacking the holding pattern, rather than *dividing his attention* between the holding stack and other aircraft in his airspace. A job aid that would help controllers prioritize tasks would enable them to develop an optimum time-sharing strategy (Sanders & McCormick, 1987).

5.6 Inappropriate Phraseology/Voice Communications

Scenario: Controller A is controlling EA234 at 10,000 ft, DL349 at 12,000 ft and EA123 at 14,000 ft all within a 10 mile radius. He issues instructions to EA234 to descend to 8,000. Due to being extremely busy, the controller does not key his transmitter long enough for the entire signal to transmit. The abbreviated call sign of "EA23" comes out on the other end. EA123 hears the clearance, acknowledges it, and descends to 8,000 ft. The controller does not hear EA123 read back the clearance and assumes that EA234 is descending. The result is less than standard separation between the three aircraft.

Causative Factors: Use of non-standard phonetics or numbers; improper usage of control instructions; homespun phraseology; poor intercom procedures; levity, non-ATC-related conversations; cut off transmissions; failure to control frequency; inattentiveness to readbacks.

Relationship to Cognitive Model: This error type corresponds to the skill-based error *stereotype takeover*. Stereotype takeover occurs when the person's attention to the original motor schema is diverted and another motor schema takes control. The controller was in a hurry and did not key the microphone long enough for the complete transmission to be issued, and then did not "hear" EA234 read back the clearance. He was not expecting EA234 to readback and therefore paid no attention when they did.

Memory Factor: The problems associated with ATC/pilot communications are well-documented (e.g., Monan, 1983). Mechanical misuse of the microphone combined with incorrect/inappropriate phraseology contributes to a variety of misunderstandings in ATC/pilot communications. Controller expectation, or, "hearing what you expect to hear" is probably the reason for missing/failing to acknowledge readbacks. A memory aid or procedure that fosters use of correct radio communication procedures would eliminate this source of operational errors.

5.7 Overuse of Automation (NAS Dependence)

Scenario: Controller A observes a radar beacon return in his airspace. Since there isn't a data tag associated with the target, nor had anyone coordinated with him, he assumes the aircraft to be below or above his terminal control airspace. He continues separating his traffic and ignores the aircraft. An incident between one of his aircraft and the unidentified, untagged aircraft occurs. The controller says, "I didn't see him.'

Causative Factors: Non-verification of essential information; lack of symbology indicating non-existence of aircraft; using information or lack of information as a causative factors when explaining "what happened".

Relationship to Cognitive Model: This error type corresponds to the skill-based error *stereotype takeover*. Stereotype takeover occurs when another motor schema takes control because the person's attention from the original schema was diverted. In this case, the controller observed the unidentified radar return, but continued with his regular control actions, forgetting about the non-tagged aircraft. in his mind, he never "saw" anything because it did not conform to his expectations (i.e., if it really was an aircraft, someone would have told him about it).

Memory Factor: The unidentified aircraft was never processed into the controller's working memory because insufficient attentional resources were devoted to it.

Controllers tend to ignore untagged radar returns. A new procedure or memory that draws controllers' attention to untagged items and forces them to ascertain whether it is an aircraft or not would eliminate this source of operational errors.

SECTION 6.0 JOB AIDS FOR AIR TRAFFIC CONTROL

In section 5.0, we discussed seven types of operational errors that result from observed controller practices. Using the cognitive model and Rasmussen's error classification scheme, we inferred the kinds of memory lapses that result from inappropriate control practices and contribute to the incidence of operational errors. In this section, we will discuss (1) general functions and purposes of job aids and (2) some of the recent research on job aids, and (3) job-aiding techniques and approaches currently being investigated by the FAA. This research is discussed to provide a sense of the scope and magnitude of job-aiding techniques, approaches and concerns that are being investigated today. In addition, we will use the controller cognitive model to match job-aiding functions to the appropriate cognitive level, and therefore, to cognitive error and memory lapses. This is done to provide a logical link between the operational problems/memory lapses discussed in Section 5.0 and the potential memory aids presented in section 7.0.

6.1 Purposes and Functions of Job Aids

Job aids are "devices which are designed to increase the human capacity for information storage and retrieval. They reduce not only the amount of decision-making necessary to perform a task, but also the need for human retention of procedures and references" (Swezey, 1987, p. 1040). Traditionally, the development of job aids has focused on tasks which involve the following of long, complicated procedures, such as maintenance or troubleshooting (Swezey, 1987). However, job aids can serve in other capacities, such as cueing, aids to association, analogs, and examples. *Cueing aids* direct the user's attention to certain characteristics of information (via highlighting, arrows, underlining, etc.) or signal the user as to what actions to take for a specific situation (e.g., checklists). *Associative aids* enable the user to look up data relating to existing information, such as code books or graphs. *Analogs* present information that cannot be displayed directly, such as schematic diagrams or mimics. *Examples* illustrate the responses required to complete a task, such as a sample form with filled in data (Swezey, 1987). *Management information systems and* *automated decision aids* are more advanced forms of job aids that enhance decision-making as well as recall of information (e.g., Sinaiko, 1977). Management information systems facilitate storage and retrieval of information, and provide time cues, triggers and models that aid rapid decision-making. Similarly, automated decision aids provide predictive data, automatic alerts and warnings, and alternative courses of action for tactical and strategic decision makers. In Table 6 we have linked these job-aiding functions to the appropriate cognitive level of performance.

TABLE 6. JOB AID FUNCTIONS AND COGNITIVE LEVEL

COGNITIVE LEVEL	JOB AID FUNCTION
SKILL-BASED	o Cueing
RULE-BASED	o Cueing o Aids to association o Analogs o Examples
KNOWLEDGE-BASED	o Management information system o Automated decision aids

Thus, job aids that provide the user with information he/she would otherwise have to retain in memory are essentially memory aids. Job aids that function as cues, aids in association, analogs, and examples are appropriate memory aids for air traffic control tasks. Procedural aids would likely not be effective because controller tasks tend to be of short duration and very dependent on the dynamic operational situation. Management information systems and decision aids are more technologically advanced versions of aids that facilitate decision-making as well as storage, search and retrieval of information.

Considerations and Approaches to the Design of Job Aids for Air Traffic Control

Most of the recent literature on development of job aids for air traffic control focused on concerns with increasing levels of automation. For example, Hopkin (1982, 1987, 1988, 1989) emphasized the impact of increasing automation on controller job satisfaction, skill development, and task structure. He asserted that the influence of future changes in the man-machine interface, such as replacing paper flight strips with electronic ones, on memory and recall of relevant data has not been fully considered. On the other hand, a potential benefit of increased automation is more efficient gathering, collating, and presenting of information. For example, the data tag associated with each aircraft depicted on the radar display could be expanded to include whether it is in level flight, climbing or descending (Hopkin, 1989).

Other researchers have systematically investigated the effects of increased automation of controller tasks on controller performance. The concern is that automation will reduce controllers' active involvement in the system, thereby impairing their knowledge and overall appreciation of system state (Narborough-Hall, 1987). Using pictorial problem-solving tasks, Narborough-Hall found that when operators adopted a passive role (more decision-making was automated) memory performance was impaired. He concluded that automation should be designed to *aid* controllers in their tasks and keep them in the control loop.

Erzberger and his colleagues at NASA-Ames (Davis, Erzberger and Bergeron, 1989; Erzberger and Nedell, 1989; Erzberger and Nedell, 1988) have developed a hierarchy of automation tools for air traffic controllers that are designed to keep controllers "in-the-loop". Using a *human-centered* automation approach, they have designed automation tools that "complement the skills of controllers without restricting their freedom to manage traffic manually" (Erzberger and Nedell, 1988, p. 2). These tools are designed to be incorporated into the new controller suites as part of the FAA's Advanced Automation System and are discussed below.

At the highest level of the automation concept hierarchy is the Traffic Management Advisor (TMA). Its primary function is to plan the most efficient landing order and to assign optimally spaced landing times to all arrivals. The TMA will assist the Center Traffic Manager in coordinating and controlling traffic between Centers, between sectors within a Center, and between the Center and Terminal Radar Approach Control (TRACON) facility. TMA also allows the Center Manager to specify runway acceptance rates and to override computer generated decisions manually (Erzberger and Nedell, 1989).

The next level of automation tools is designed for Center controllers who handle descent traffic that flows into the TRACON. The Descent Advisor (DA) is driven by the output of TMA, receiving the specified gate arrival time for each aircraft passing through the arrival sector. The DA provides the controller with continually updated advisories which they can use to keep the aircraft on time (Erzberger and Nedell, 1988).

The third automation tool is designed for TRACON controllers who take over control of traffic at feeder gates. These controllers merge the traffic converging on the final approach path and make sure the aircraft are properly spaced. If the center controllers have delivered the aircraft at the feeder gates at correct times using the DA, then the TRACON controllers will normally need to make only minor corrections to achieve the desired spacing. The Final Approach Spacing Tool (FAST) assists the TRACON controller in making these minor corrections with high accuracy and a minimum of heading vectors and speed clearances (Davis, Erzberger and Bergeron, 1989).

All of these automation tools incorporate an interactive graphical interface that allows the controller or manager to select a desired level of computer assistance. For example, the controller can use the tools to gain insight into the effect of planned actions, or he/she can use the tools to issue computer generated clearances to the aircraft. The research and ideas discussed above (e.g., Hopkin, 1989; Narborough-Hall, 1987) has shown that keeping the controller active and "in-the-loop" is an essential component to the success of new automation. However, a primary concern is the development of aids that controllers can use in the *present* ATC system to help meet increasing traffic loads.

Engineers at MITRE Corporation have developed one aid that addresses this goal (Mundra, 1989). The display aid is designed to help arrival controllers conduct converging, staggered approaches to the runway. Converging staggered approaches are used at some airports, but they present a difficult task and high workload for controllers. The display aid, called the "ghosting" display, converts the converging approaches geometry to simulate a single runway approach geometry. For example, suppose Approach A and Approach B are the final approach paths for two intersecting runways. Each has three aircraft along these approach paths (A1, A2, A3 and B1, B2, B3). The ghosting display puts reference images of A1, A2 and A3 along Approach path B such that the distance of reference image A1 from runway threshold B is equal to the distance of aircraft A1 from runway threshold A. As aircraft progress on Approach A, their reference images progress on Approach B by the same amount. This display aid effectively transforms the problem of controlling converging runway approaches to that of controlling a single runway. The ghosting display is currently being field tested by the FAA and may be implemented by 1992 (Mundra, 1989).

A third approach to the design of job aids is found by going to the controllers themselves and asking, "What informal procedures/techniques/devices do you use now as aids to memory?" Once this information is gathered, a systematic evaluation of effectiveness of each aid could be determined. This kind of survey approach was unfortunately outside the scope of this project. However, we did accomplish a limited, informal survey of this nature at a nearby facility, and also used subject matter expertise to determine effective memory aids that controllers have used in the past. These ideas provide the foundation for some of the aids that we propose in the next section.

SECTION 7.0 POTENTIAL CONTROLLER MEMORY AIDS

For each operational problem area and its associated memory/cognitive errors, we have identified potential memory aids. Some of these aids are based on informal procedures/techniques that controllers past and present have used as "memory joggers". Other aids are suggested by literature findings that indicated the need for manual backup systems to keep controllers active and "in-the-loop" (e.g., Hopkin, 1982). The remaining aids are being developed by other researchers for NASA and/or the FAA. In this section, we will describe each memory aid and discuss how each addresses a particular memory problem area (see Table 7 at the end of this section). There is no one-to-one correspondence between memory aids and problem areas -- they often overlap. Where possible, we have provided figures and illustrations of the potential memory aids.

7.1 Descriptions of Potential Memory Aids

1. CAN-Handoff Check off Blocks on Flight Strips. These are four additional blocks proposed to be added to flight strips. Four boxes with the letters **C**, **A**, **N**, and **H** will be preprinted on strips. Controllers check off each block as the task that it represents is completed:

   C - Clear of all conflicting traffic
   A - Climbing/descending or at assigned Altitude
   N - Predetermined radar vector or on own Navigation
   H - Handoff to adjacent controller, sector, or facility.

   (See Figure 5 for illustration of CAN-Handoff blocks strip.

   The first three boxes, marked C, A, and N are checked off when each respective item has been addressed by the controller (they can be checked off in any order). Once all three items, or tasks, are accomplished to the controller's satisfaction, the controller then hands off the aircraft to the next controller, sector, or facility. If the aircraft is on a radar vector, the controller must ensure that he has communicated this information to and coordinated with the next controller to handle the aircraft.

   Mandated use of the CAN-Handoff check off blocks forces the controller to *ensure* that each of these three items (represented by C, A, and N) has been taken care of prior to handing off the aircraft. The check off blocks also serve as a *reminder* or back-up of which tasks have been satisfactorily completed and which remain to be accomplished. Criteria for

FIGURE 5. CAN-HANDOFF CHECK OFF BLOCKS ON FLIGHT STRIP

ABC828	C	1777	PHL	PHL MXE MXE278 PENSY J48			
	A						
DC9/A	N	P1730		EMI GVE SBV2 RDU			
319	H	280					

checking off each block will probably vary from situation to situation; these criteria need to be identified before use of the CAN-Handoff check off blocks can be systematically investigated.

The CAN-Handoff check off blocks were designed so that the letters "CAN" provide an easy to remember mnemonic device for the controller. Both new and experienced controllers can be quickly taught what each letter stands for, and training for this new procedure should be minimal (once the conditions for checking off each block are identified). The mnemonic "CAN" could potentially become another term in controller lingo, for example, "Is that aircraft CANned yet?"

Because the blocks can be checked off individually at any point in time while the aircraft is under his control, use of the CAN-Handoff blocks can be adapted to suit various controller strategies. For example, in a low workload situation where the controller has just a few aircraft under his control simultaneously, he may employ a strategy that utilizes more refined and coordinated control solutions (e.g., expeditious routings), requiring him to process more data per aircraft, which then takes more time and attentional resources. The controller can mark off each block at his leisure, as he completes each item represented by the block. If he is distracted by another task during this process, or should there be any interruption of automated data on his radar presentation, the block(s) already checked off provide a backup or record of what he has already done, and he can easily pick up where he left off. Alternatively, under medium and high workloads where the controller will use more standardized routings and control procedures, or is working with a holding pattern, he can quickly perform and check off the three required blocks (C, A, and N) before making the handoff or before directing his attention to the next aircraft.

While it is proposed here that use of the CAN-Handoff check off blocks will reduce memory load in all of low, medium and high workload situations, the actual effect may prove to be the opposite under certain high workload conditions. It is strongly recommended that use of these check off blocks be thoroughly investigated in an experimental setting.

The CAN-Handoff procedure is designed to be used in the existing NAS, but is also designed to be implemented in a fully automated system. The four checkoff blocks can be incorporated into the electronic flight strips designed for the Advanced Automation System (AAS). In a fully automated scenario, this places the controller in an active participant role rather than in a monitoring function. The controller will be alert and able to intervene should a non-standard situation or emergency present itself.

2. Timesharing of data on data block using quick look feature or trackball slew. The data block for each identified aircraft on the radar scope indicates the aircraft call sign, its present altitude and present airspeed. Additional information can be "timeshared" and presented in the data block once it is

entered into the ARTS computer. The proposed additional information should include last assigned altitude, last assigned heading, and an arrow to indicate whether the aircraft is climbing or descending (no arrow if the aircraft is maintaining). For arrival aircraft when control is being passed to the tower, additional, timeshared information should include runway assignment and type of aircraft. The controller can access this information by an alphanumeric keyboard entry ("quick look") or by slewing the trackball out to the target and pressing enter or a function key. (See Figure 6a, 6b and 6c for illustrations of Timesharing data blocks.)

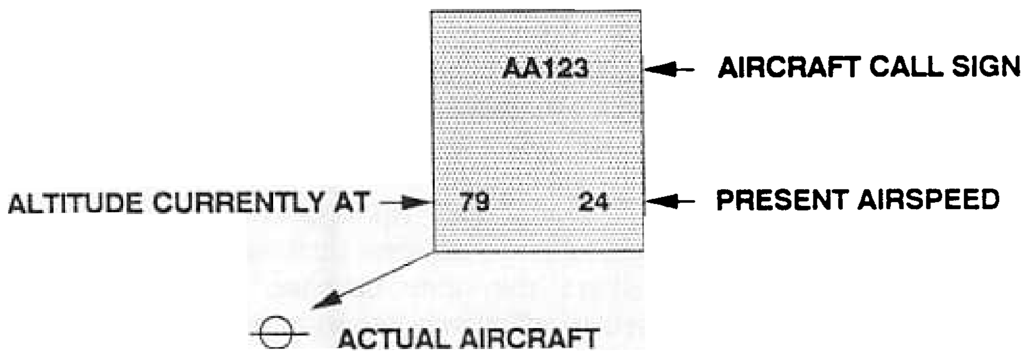
3. System Atlanta Information Displaying System. An air traffic control management information system, such as System Atlanta Information Displaying System (SAIDS), could be installed on networked personal computers and located at various control and supervisory positions. System Atlanta is a menu-driven system that can be custom-designed for individual facilities. It provides information such as position relief checklists, composite weather, equipment outages, Center flow restrictions, special activities, weather forecast, center, tower, and TRACON frequencies, navaids, center sector configurations, approach altitudes and minima, holding patterns, missed approach procedures, emergency procedures, and emergency phone numbers. Additional menus can be added or deleted depending on individual facility requirements. The total capacity is 250 "pages" or menu options.

All the information that SAIDS can provide through simple menu selections is data that controllers normally have to spend time and attentional resources to locate. Usually this information is provided in binders that controllers check before signing on, or large status boards placed in a central location in the control room. The advantages of an automated system such as System Atlanta over the traditional methods are: (a) information can be instantly updated, (b) all controllers have easy access to important data via simple menu selections -- they do not have to completely draw their attention away from the radar scope, (c) temporary information such as frequency changes are stored electronically (versus on paper) and thus cannot be thrown away prematurely, (d) it provides easy access to infrequently used and emergency information. The overall advantage is that the system provides controllers with easy access to important ATC information. This, in turn, allows controllers to concentrate on decision-making and control actions, rather than searching for needed data.

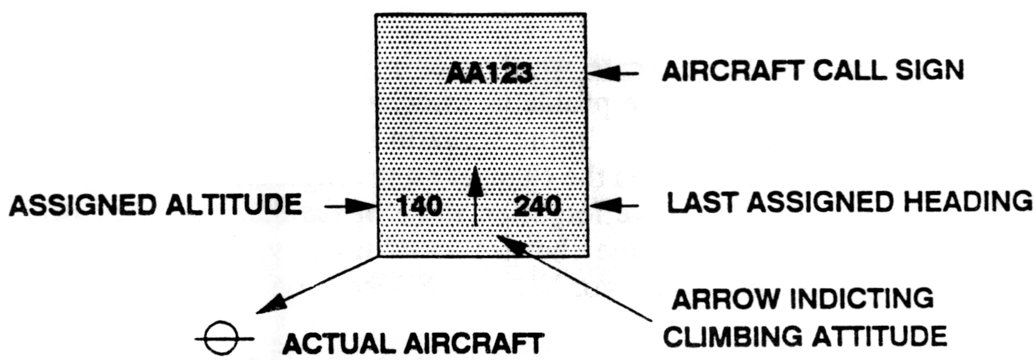
4 Non-automated Handoff. Reverting to a non-automated handoff in which the controller must slew to the target and hit enter to accept the aircraft provides the following advantages: (a) controller can ensure the aircraft has the right transponder code, (b) if an aircraft is on the wrong transponder code, it allows enough time for the pilot to realign the transponder code or change to backup

FIGURE 6. TIME SHARE INFORMATION IN DATA BLOCK

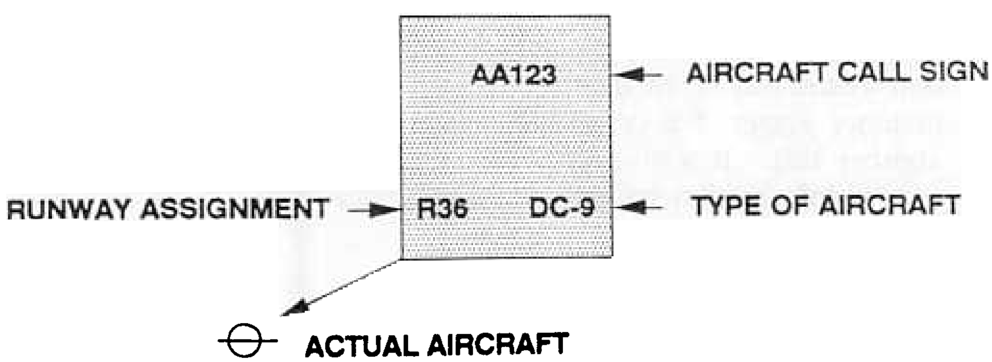
6a. ALPHA NUMERIC (A/N) DATA BLOCK



6b. TIME SHARE (A/N) DATA BLOCK FOR TRACON & CENTER



6c. TIME SHARE (A/N) DATA BLOCK FOR TRACON TOWER



equipment, and (c) ensures the aircraft will not go through the airspace undetected. Non-automated handoffs force the controller to focus his attention on the aircraft, thus reducing the chance he will forget about them.

5. Color coding of flight strip holders for route direction. This can be used in centers and TRACONS to indicate route of flight and direction of departure/arrival, respectively. For example, in the Center, one color should be used for North/East flights and another color for South/West flights. This should minimize the amount of time controllers spend scanning the strip bay looking for a particular flight, thus, allowing more time for decision-making tasks. Color coded strip holders should also aid the controller in organizing and maintaining his flight strip data, making housekeeping easier.

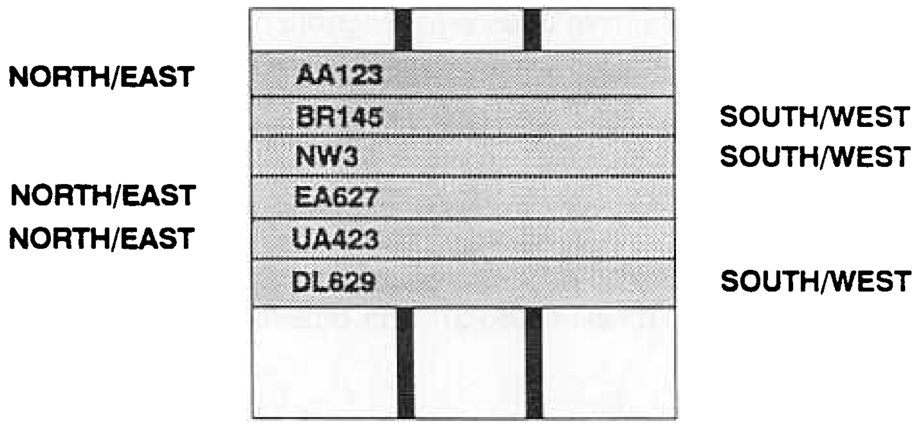
6. Enlarged Strip Bays. Expansion of the strip bays so that strip can be offset to the right or to the left will help two adjacent final controllers organize their flight strips when they share the same airspace. In centers, the bay modification could be used to effectively separate North/East flights from South/West flights. This bay modification coupled with color coded strip holders would reduce the amount of valuable time and attention spent scanning, which takes away from the controllers' primary task of separating aircraft. (See Figures 7a and 7b for illustrations of strip bays.)

Use of Red to indicate warning or revision on flight strips. This would eliminate some of the problems associated with updating flight strip data, if it is used consistently. In the scenario in Section 5.2, if the Assistant Local Controller had marked the changes on the flight strips **immediately**, using red, then he wouldn't have forgotten some of the data and the Local Controller would have noticed the changes. Additional verbal coordination, although recommended, would not have been necessary.

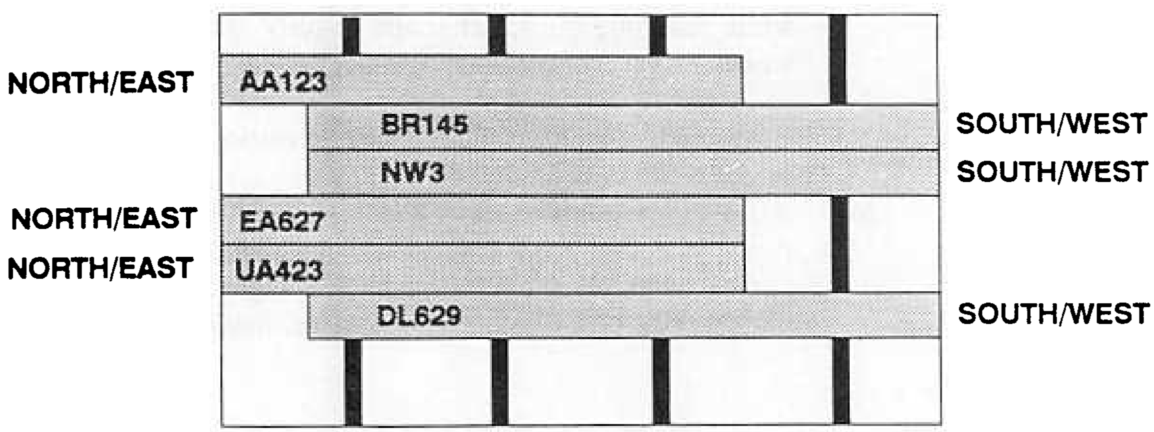
8. Voice Recognition System/Tape Readback. The primary function would be to alert controllers by either a visual or auditory signal that a prior transmission was cut short or a call sign transposed. If the controller utters an incomplete or incorrect aircraft call sign, the system would recognize that an error occurred and would alert the controller. In addition, the system would allow controllers to play back prior transmissions should any doubt exist that clearances were incorrectly issued or received. It would serve as a memory jogger if a controller was distracted or his attention diverted to another task. It would also allow other controllers/supervisors to retrieve control information instantly without having to switch from one recorder to another, as is the current practice.

FIGURE 7. MODIFICATION OF STRIP BAYS

7a. PRESENT TRACON/CENTER BAY STRUCTURE



7b. PROPOSED TRACON/CENTER BAY STRUCTURE



9. Installation/Color Coding of strip chutes from Tower to TRACON. Some facilities already have strip chutes -- the feasibility of installing them in more facilities should be investigated. In addition, strip chutes can be color coded, using the same scheme as for strip holders. This should prevent the receipt of incorrect/unrevised flight strips in the TRACON. It minimizes the possibility of having inactive strips in front of the controller, reducing potential for confusion. When the controller receives the strip, he will know it is active.

10. Strip Location Format. This provides a standardized method for placing flight progress strips in front of terminal controllers. Departure/arrival controllers would place the aircraft closest to the airport at the bottom of the departure lineup (bottom of the bay). By scanning from the bottom up, controllers would have an instant recollection of the aircraft's position, as well as manual backup system should an ARTS failure occur. At facilities with two final controllers, the final controllers would place the aircraft closest to the airport at the top of the arrival lineup. This system, used in conjunction with offset strip holders, would minimize confusion resulting from a rapidly changing traffic picture. It would also assist in establishing a more accurate approach lineup.

Challenge-response Checklist. This is a checklist similar to aircraft checklists and is proposed for position relief briefings. When an item on the checklist has been addressed by both controllers, the lever is moved from left to right and the word "Completed" appears. This will ensure that the controller being relieved passes all pertinent information to the relieving controller. Position relief briefing should be a three-step process:

(1) Relieving controller should plug in and listen for two minutes while scanning the radar scope to fully identify all traffic being worked by the controller being relieved.

(2) Both controllers perform challenge-response checklist.

(3) After list is completed, relieved controller should plug in for two minutes to ensure that relieving controller has the picture and is controlling all traffic. (See Figure 8a, 8b, and 8c for illustrations of a Challenge-response checklist sequence.)

FIGURE 8a. CHALLENGE-RESPONSE CHECKLIST AT BEGINNING OF POSITION RELIEF BRIEFING

POSITION RELIEF CHECKLIST

1. EQUIPMENT - Status/Alignment
2. AIRPORT ACTIVITIES - (Mowing/Construciton)
3. FLOW RESTRICTIONS
4. SPECIAL ACTIVITIES - (Parachute Jump
   Flight Check
   Special Mission
   Air Show)
5. APPROACH/FIELD INFORMATION
6. SPECIAL INSTRUCTIONS - (Combined Positions)
7. STAFFING - (Handoff Positions)
8. TRAINING - (On what Positions)
9. CONTROL INFORMATION

FIGURE 8b. CHALLENGE-RESPONSE CHECKLIST WHEN FIRST FOUR ITEMS HAVE BEEN CHECKED

POSITION RELIEF CHECKLIST

1. COMPLETE
2. COMPLETE
3. COMPLETE
4. COMPLETE

5. APPROACH/FIELD INFORMATION
6. SPECIAL INSTRUCTIONS - (Combined Positions)
7. STAFFING - (Handoff Positions)
8. TRAINING - (On what Positions)
9. CONTROL INFORMATION

FIGURE 8c. CHALLENGE-RESPONSE CHECKLIST WHEN ALL ITEMS HAVE BEEN COMPLETED

POSITION RELIEF CHECKLIST

1. COMPLETE
2. COMPLETE
3. COMPLETE
4. COMPLETE

5. COMPLETE
6. COMPLETE
7. COMPLETE
8. COMPLETE
9. COMPLETE

12. Indicator Light System. This would serve as a visual reminder that control instructions have been issued and further acknowledgement is pending (red) or is not required (green). The indicator lights should be installed in TRACONS and towers and used for departures. For example, when the aircraft is airborne and Departure Radar has acquired the aircraft, he will flip the switch to green so that the tower knows he has acquired and can accept another aircraft. Similarly, the light system can be installed in the tower and used for runway crossings. When Ground Control asks Local Control for a runway crossing, Local Control (or the assistant) flips the switch to red, indicating runway in use. When the pilot reports clear of the runway to Ground Control, Ground Control flips it back to green, indicating clear of the runway. The lights would be set up along a mimic of the runways to that the runway in question would be indicated. (See Figures 9a, 9b and 9c for illustrations of Indicator Light System.)

13. "Ghosting" display. This display aid is designed to help arrival controllers conduct converging, staggered approaches to the runway, and is meant to increase airport capacity. The ghosting display converts the converging approaches geometry to a single runway geometry by displaying reference images of the Approach A aircraft on Approach B. As aircraft progress on Approach A, their reference images progress on Approach B by the same amount. In effect, the display aid transforms the problem of controlling converging runway approaches to that of controlling a single runway.

14. Traffic Management Advisor (TMA). The primary function of TMA is to plan the most efficient landing order and to assign optimally spaced landing times to all arrivals. It will assist the Center Traffic Manager in coordinating and controlling traffic between Centers, between sectors within a Center, and between the Center and Terminal Radar Approach Control (TRACON) facility. TMA allows the Center Manager to specify runway acceptance rates and to override computer generated decisions manually.

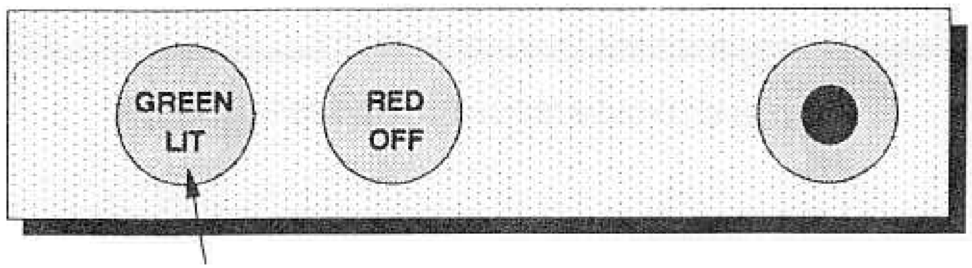
15. Descent Advisor (DA). DA is driven by the output of TMA, receiving the specified gate arrival time for each aircraft passing through the arrival sector. The DA provides the controller with continually updated advisories which they can use to keep the aircraft on time.

FIGURE 9. INDICATOR LIGHT SYSTEM

a. BEGINNING PHASE

TOWER INDICATOR PANEL

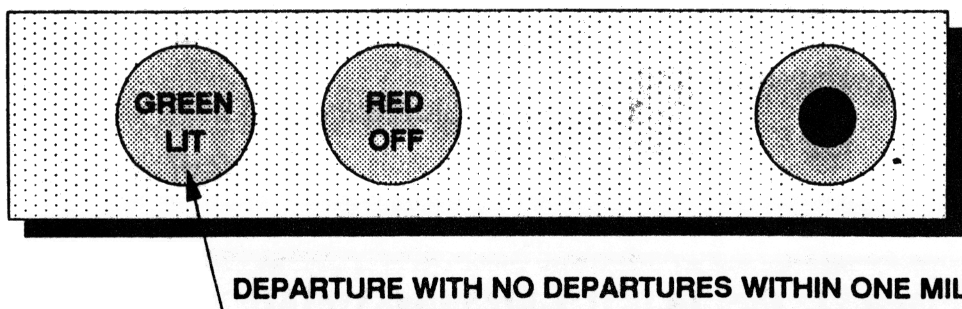
PUSHBUTTON



TOWER INDICATOR PANEL WITH NO DEPARTING AIRCRAFT
NO AIRCRAFT CROSSING ANY RUNWAY

DEPARTURE/GROUND CONTROL INDICATOR PANEL

PUSHBUTTON



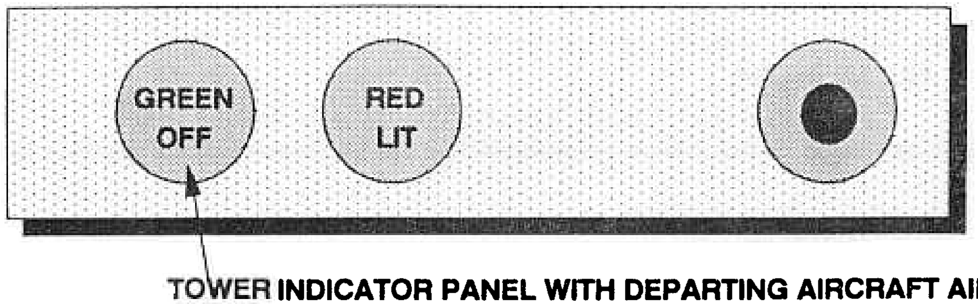
DEPARTURE WITH NO DEPARTURES WITHIN ONE MILE OF RUNWAY
GROUND CONTROL WITH NO AIRCRAFT CROSSING ANY RUNWAY

FIGURE 9. INDICATOR LIGHT SYSTEM

b. INTERMEDIATE PHASE

TOWER INDICATOR PANEL

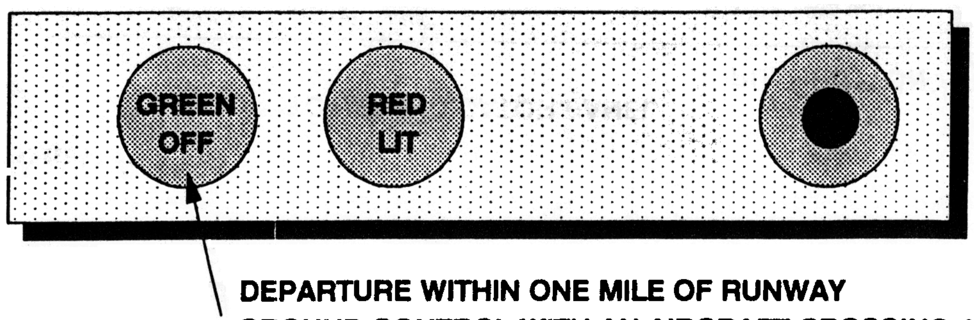
PUSHBUTTON



TOWER INDICATOR PANEL WITH DEPARTING AIRCRAFT AIRBORNE
WITH AIRCRAFT CROSSING ANY RUNWAY

DEPARTURE/GROUND CONTROL INDICATOR PANEL

PUSHBUTTON



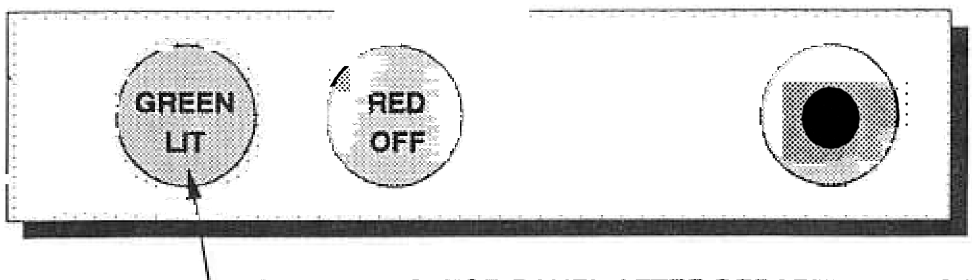
DEPARTURE WITHIN ONE MILE OF RUNWAY
GROUND CONTROL WITH AN AIRCRAFT CROSSING ANY RUNWAY

FIGURE 9. INDICATOR LIGHT SYSTEM

c. FINAL PHASE

TOWER INDICATOR PANEL

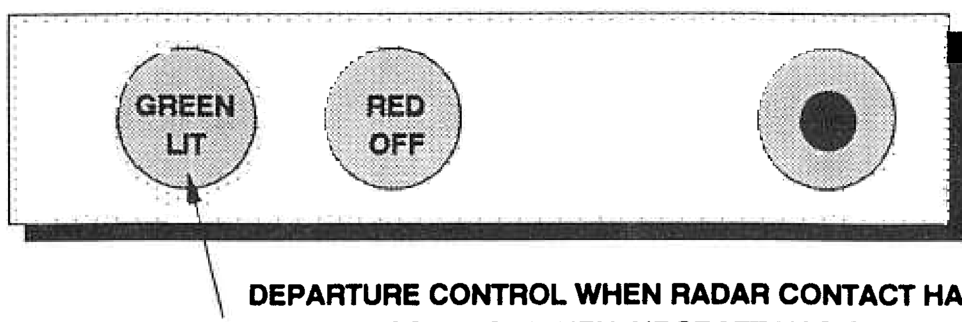
PUSHBUTTON



TOWER INDICATOR PANEL AFTER DEPARTURE HAS RADAR CONTACT
AFTER CROSSING AIRCRAFT HAS CLEARED RUNWAY

DEPARTURE/GROUND CONTROL INDICATOR PANEL

PUSHBUTTON



DEPARTURE CONTROL WHEN RADAR CONTACT HAS BEEN ESTABLISHED
GROUND CONTROL WHEN AIRCRAFT HAS COMPLETED CROSSING RUNWAY

16. Final Approach Spacing Tool (FAST). FAST is designed for TRACON controllers who merge the traffic converging on the final approach and make sure the aircraft are properly spaced. If Center controllers have delivered the aircraft at feeder gates at correct times using the DA, then the TRACON controllers will normally need to make only minor corrections to achieve the desired spacing. FAST assists the TRACON controllers in making these minor corrections with high accuracy and a minimum of heading vectors and speed clearances.

7.2 Operational Error Categories and Potential Memory Aids

1. Controlling aircraft in another's airspace. This type of error results from lack of proper coordination procedures and attempting to expedite traffic movement. There are five memory aids that address this type of error:

   (a) *CAN-Handoff Checkoff Blocks on flight strips* - Use of this checklist serves as a reminder and a cueing aid to conform to prescribed procedures.

   (b) *Timeshared data in data block* - Alerts controller A of controller B's intentions, thereby allowing time for changing plans or to challenge controller B's decision. Minimizes confusion as to what control actions other controllers are taking that may affect your decisions.

   (c) *Traffic Management Advisor/Descent Advisor/Final Approach Spacing Tool* - Provide automated procedures to fix aircraft on predetermined routes eliminating shortcutting route of flight.

2. Processing flight data manually inter/intra-facility. This category of operational errors result from delays or failures to process information, improper sequencing of active data, relying on recall and not taking notes, and poor housekeeping. Six potential memory aids address this category of operational errors:

   System Atlanta information system - minimizes delays in processing information. Control information (i.e., runways in use) is always current and easily accessed. Reduces reliance on recall memory.

   Challenge-response checklist - eliminates relying on recall memory when relieving or being relieved from control position.

Color-coded flight strip holders - Minimizes errors due to placement of strip holders in the wrong sector. Eliminates confusion and delays due to receipt of incorrect flight strips.

Strip location format - minimizes errors due to improper processing or sequencing of active data.

Enlarged strip bays - minimizes time spent searching for active strips when two controllers share the same airspace.

(f) *Red as warning on flight strips* - alerts controllers of impending problem. Minimizes delay in acting to correct a problem.

3. Inter/intra-facility coordination. This category of operational errors results from inappropriate use of the intercom, assuming messages have been received when there is no verbal acknowledgement, issuing clearances into another sector's airspace without permission, and failure to verify message information. The following six potential aids address this category of errors:

Timeshared data on data block - alerts all controllers of a controller's intentions, thereby allowing more time for changes in plans. Reduces the amount of verbal coordination between controllers.

Non-automated handoffs - Eliminates assuming a handoff has been made. Allows controller to decide when he/she wants to relinquish control of a particular aircraft. Eliminates possibility of controller making a handoff prematurely or erroneously.

Color-coded strip holders - Eliminates confusion and increased coordination resulting when two controllers receive the wrong strips.

Indicator light system - Verifies receipt of active data on a flight. Minimizes possibility of forgetting about an aircraft. Serves as a backup to voice communication.

Strip location format - Allows other controllers and supervisory personnel to quickly compose the traffic picture when changing positions and/or combining positions.

4. Assuming separation will exist. This category of errors results from incorrect control procedures such as using Mode C altitude readout of aircraft not under control as barometer for issuing clearance, assuming information

presented is factual, lack of positive control, not issuing traffic information in a timely manner. There are five potential memory aids that address this problem:

(a) *Timeshared data in data block* - alerts all controllers of a controller's intentions, there by allowing more time for changing plans and/or challenging his decision.

(b) *Ghosting display* - Minimizes improper control decisions when controlling approaches on converging runways. Provides a tool for proper spacing of approach traffic.

(c) *Traffic Management Advisor/Descent Advisor/Final Approach Spacing Tool* - These automated tools provide automated procedures to separate all flights. Minimizes use of improper control procedures and decisions.

5. Improper radar/visual scanning. This category of errors results from inattention or lack of discipline in updating/scanning radar display or traffic patterns for potential conflictions, focusing attention in one quadrant of radar scope or traffic pattern when events dictate complete scanning, inappropriate mental checklists while scanning radar displays/traffic patterns, thus failing to understand what is seen. Seven potential memory aids address this problem:

(a) *Timeshared data in data block* - The additional information in the data block (last assigned altitude, heading, and arrow indicating climbing or descending) will help controllers understand their own as well as other controller's traffic picture.

(b) *CAN-Handoff check off blocks on flight strips* - Use of the checklist helps controller maintain awareness of entire traffic pattern. Serves as a reminder to conform to prescribed procedures and to scan entire scope or traffic pattern.

(c) *Ghosting display* - Aids approach controllers who are merging traffic onto converging runways. Simplifies the problem of merging traffic from two approaches into simply controlling traffic on one approach.

(d) *Traffic Management Advisor/Descent Advisor/Final Approach Spacing Tool* - Provide automated procedures, reminders and warnings for separating traffic. Eliminates errors resulting from failing to properly scan the scope or traffic pattern.

Red as warning on flight strips - Alerts controller to impending problem. Minimizes delay in acting to correct problem.

6. Inappropriate phraseology and improper voice communications. This type of operational error results from use of nonstandard phonetics or numbers, improper use of control instructions, homespun phraseology, poor intercom/microphone procedures, levity and non-ATC-related conversations, cut off transmissions, failure to control frequency, and inattentiveness to readbacks. One memory aid addresses these communication errors:

    Voice recognition system/play back - Alerts controller when he transposes call sign numbers or gives an incorrect/abbreviated call sign. Use of play back allows controller to correct inappropriate transmissions.

    Also recommend increased controller awareness of inappropriate phraseology/voice communications through training, staff discussions, and increased supervisory control and awareness.

7. Over use of automation (NAS Dependence). This group of operational errors result from improper procedures such as non-verification of essential information, failure to assign proper priority to the exchanging of essential traffic information, lack of symbology indicating non-existence of aircraft, relying on the automated system to provide control solutions, invalidation of Mode C readout, lack of stripmarking to assist in the event of system failure, and using information or lack of information as a causative factor when explaining "what happened". There are five memory aids that address this problem:

    CAN-Handoff check-off blocks on flight strips - Use of the checklist serves as a reminder to conform to prescribed procedures.

    Timesharing of data in data block - alerts all controllers of a controller's intentions, thereby allowing more time for changing plans.

    Non-automated handoff - allows a controller to decide when he/she wants to relinquish control of a particular aircraft. Keeps the controller actively involved. Prevents an aircraft from taking off on the wrong transponder code, resulting in no ARTS tag.

(d) *Indicator light system* - provides a visual signal that serves as a reminder that control instructions have been issued and further acknowledgement is pending (red) or is not pending (green).

(e) *Voice recognition system* - allows controller to play back previous transmissions should he forget or doubt that he/she gave the correct clearance instructions.

TABLE 7. OPERATIONAL PROBLEMS AND POTENTIAL MEMORY AIDS

	OPERATIONAL PROBLEM	POTENTIAL MEMORY AIDS
1.	Controlling aircraft in another's airspace.	o CAN-Handoff o Timesharing data in data block o DA, FAST, & TMA
2.	Processing flight data manually inter/intra-facility.	o System Atlanta Information Displaying System o Challenge-response checklist o Color-coded stripholders o Strip location format enlarged strip bay o Red as warning
3.	Inter/intra-facility coordination.	o Timesharing data in data block o Non-automated handoff o Color-coded stripholders o Strip location format o Indicator light system o Strip chute
4.	Assuming separation will exist.	o Timesharing data in data block o Ghosting display o DA, FAST and TMA
5.	Improper radar/visual scanning.	o Timesharing data in data block o CAN Handoff o Ghosting display o DA, FAST and TMA o Red as warning
6.	Inappropriate phraseology/Voice Communication.	o Voice recognition system o Increased controller awareness
7.	Overuse of automation.	o CAN-Handoff o Timesharing data in data block o Non-automated handoff o Indicator light system o Voice recognition system

SECTION 8.0 EVALUATION OF MEMORY AIDS

The potential memory aids presented in Section 7.0 were subjectively evaluated using the following criteria: face validity, usability, feasibility, effectiveness, cost, and testability. (See Table 8 for definitions.) For each criteria, qualitative ratings of Low, Medium, and High or Easy, Medium, Difficult were used to evaluate the memory aids. The criterion Face Validity, i.e., will controllers accept and use the aid, was broken down by inexperienced controllers and experienced controllers. We expected that controller attitudes towards new ideas and procedures would be different. Inexperienced controllers would be more accepting of new ideas, whereas experienced controllers would be less accepting.

The purpose of the evaluation was to screen the memory aids and determine the most effective, feasible, and testable aids for Year 2 experiments in this project. Based on the evaluation results, ordinal rankings were assigned to each memory aid. For example, Descent Advisor (DA) is highly effective as a memory aid, but requires costly new equipment, new training and procedures. DA is currently being evaluated by NASA and the FAA for installation in the Advanced Automation System, therefore, this memory aid was ranked low. CAN-Handoff, on the other hand, is also highly effective, would be relatively easy and inexpensive to implement, and would require minimal training. Based on the evaluation criteria and the need to find memory aids that would fit into the existing NAS equipment configuration, this memory aid was ranked high.

The results of our evaluation are presented in Table 9. A brief description of each memory aid in terms of what it accomplishes and our recommendations for testing in the second year are provided in Table 10.

TABLE 8. KEY TO EVALUATION CRITERIA

FACE VALIDITY	(a) Will inexperienced controllers accept and use the aid (b) Will experienced controllers accept and use the aid	
	HIGH	Very likely
	MED(IUM)	Somewhat likely
	LOW	Not likely
USABILITY	How much training is required to effectively use the aid.	
	EASY	Little training required
	MED(IUM)	Some training required
	HARD	Lots of training required
FEASIBILITY	Given existing hardware/software, how easily can the aid fit into current configuration.	
	EASY	Can be easily and quickly installed
	MED(IUM)	Requires some modification to existing equipment
	HARD	Requires major modifications to existing equipment and/or new equipment
EFFECTIVENESS	How effectively does the aid address memory limitations and associated system errors.	
	HIGH	Highly effectively
	MED(IUM)	Somewhat effective
	LOW	Not very effective
COST	What is the relative cost of purchase, installation and training.	
	HIGH	High cost
	MED(IUM)	Medium cost
	LOW	Low cost
TESTABILITY	How "testable" is the aid for Year 2 experiments of this project.	
	HIGH	Very testable due to low cost and testing feasibility
	MED(IUM)	Fairly testable
	LOW	Not very testable due to high cost and/or complexity of testing

TABLE 9. RESULTS OF MEMORY AIDS EVALUATION

MEMORY AIDS	FACE VALIDITY		USABILITY	FEASIBILITY	EFFECTIVENESS	COST	TESTABILITY	RANKING
	INEXP	EXP						
1. CAN-HANDOFF	HIGH	MED	EASY	EASY	HIGH	LOW	HIGH	1
2. TIMESHARED DATA IN DATA BLOCK	HIGH	MED	EASY	MED	HIGH	MED	HIGH	2
3. SYSTEM ATLANTA INFO SYSTEM	HIGH	HIGH	MED	MED	HIGH	HIGH	HIGH	3
4. NON-AUTOMATED HAND-OFF	HIGH	MED	MED	EASY	HIGH	LOW	HIGH	4
5. COLOR-CODED STRIPHOLDERS	HIGH	MED	MED	EASY	MED	LOW	HIGH	5
6. ENLARGED STRIPBAYS	HIGH	MED	EASY	MED	MED	MED	HIGH	6
7. RED AS WARNING ON STRIPS	HIGH	MED	EASY	EASY	LOW	LOW	LOW	7
8. VOICE RECOGNITION SYSTEM	HIGH	HIGH	EASY	MED	HIGH	MED	HIGH	8
9. STRIP CHUTE	HIGH	HIGH	EASY	MED	HIGH	HIGH	LOW	9
10. STRIP LOCATION FORMAT	HIGH	LOW	EASY	EASY	LOW	LOW	LOW	10
11. CHALLENGE-RESPONSE CHECKLIST	HIGH	MED	EASY	MED	MED	MED	MED	11
12. INDICATOR LIGHT SYSTEM	HIGH	MED	HARD	MED	MED	MED	MED	12
13. "GHOSTING DISPLAY"	HIGH	HIGH	MED	HARD	MED	HIGH	MED*	13
14. TRAFFIC MANAGEMENT ADVISOR	HIGH	HIGH	HARD	HARD	HIGH	HIGH	LOW*	14
15. DESCENT ADVISOR	HIGH	HIGH	HARD	HARD	HIGH	HIGH	LOW*	15
16. FINAL APPROACH SPACING TOOL	HIGH	HIGH	HARD	HARD	HIGH	HIGH	LOW*	16

*Already being investigated by FAA or NASA

TABLE 10. SUMMARY OF MEMORY AIDS AND RECOMMENDATIONS

MEMORY AIDS	WHAT CAN BE ACCOMPLISHED	RESULTS OF SCREENING
1. CAN-Handoff - Blocks added to correct flight strips	o Provides written record of all control actions taken for each aircraft. o Minimizes possibility of forgetting to accomplish each of the tasks represented in the check-off blocks. o Eliminates possibility of forgetting whether an aircraft is on own navigation or radar vector, and whether aircraft has final assigned altitude. o Should be used with Job Aid #2.	Highly recommended for testing.
2. Timesharing data block using a quick look feature or "slew"	o Provides information on last assigned altitude, last assigned heading and whether aircraft is climbing or descending (indicated by arrows). o Minimizes problems associated with inter/intrafacility coordination. o Minimizes number of facts controller must retain in working memory.	Highly recommended for testing.
3. System Atlanta or other information-displaying scope	o Minimizes number of items must be retained in working memory. o Provides easy access to rarely-used procedures, runway and weather conditions, approaches in use.	Highly recommended for testing.

TABLE 10. SUMMARY OF MEMORY AIDS AND RECOMMENDATIONS

MEMORY AIDS	WHAT CAN BE ACCOMPLISHED	RESULTS OF SCREENING
4. Reverting back to non-automated radar hand-offs	o By reverting back to a non-automated handoff, it becomes impossible for an aircraft to take off on the wrong transponder code (resulting in no ARTS tag). o Allows the controller to decide when he wants to relinquish control of a particular aircraft; eliminates possibility of the computer making a handoff prematurely/erroneously. o Keeps the controller actively involved. o Should be used with Job Aids #1 and #2.	Highly recommended for testing.
5. Color-coding for route direction	o Provides immediate indication of route of flight/direction of departure or arrival. o Minimizes the time spent scanning the strip bay to locate a particular strip; allows more time for decision-making tasks. o In terminals, minimizes possibility of receiving a strip that should have been given to another controller.	Highly recommended for testing.
6. Enlarging strip holder bays to allow for offsetting strips	o Minimizes (by 50%) strip bay scanning time; this allows controllers to keep more of their attention on the radar scope. o Should be used with Job Aid #5.	Highly recommended for testing.

TABLE 10. SUMMARY OF MEMORY AIDS AND RECOMMENDATIONS

MEMORY AIDS	WHAT CAN BE ACCOMPLISHED	RESULTS OF SCREENING
7. Color red to indicate warning/revision to route of flight, altitude or holding path	o Forewarns controller of impending problem; provides an alert indication. o In centers, alerts attention of controller team so that other controllers may assist if primary controller is distracted or has excessive workload.	Recommended for testing.
8. Voice recognition system/playback	o Provides visual or auditory signal to alert controller when incorrect or abbreviated call sign was transmitted. o Allows controller to play back previous transmission if unsure they were correctly transmitted or received.	Highly recommended for testing.
9. Strip chutes between towers and tracons	o Minimizes verbal communications between local controller and Departure Radar Controller. o Eliminates strip duplication and receipt of unrevised strips; when strip is received, controller knows it is active. o Can be used with Job Aids #4, 5 and 12.	Highly recommended for testing.
10. Formatting or mandating how strips are placed in strip bays	o Allows controller to quickly ascertain an aircraft's position in relation to the airport. o Allows other controllers and supervisory personnel to quickly compose the traffic picture when changing positions and/or combining positions.	Highly recommended for testing.

TABLE 10. SUMMARY OF MEMORY AIDS AND RECOMMENDATIONS

MEMORY AIDS	WHAT CAN BE ACCOMPLISHED	RESULTS OF SCREENING
11. Challenge response checklist similar to aircrew lists for position relief briefings	o Minimizes possibility of controller being relieved of forgetting to pass on information. o Engages both controllers in coordinating transfer of traffic picture from one to the other.	Recommended for testing.
12. Indicator light system (green vs. red) to signify "safe to use" vs "in use"	o Provides a visual signal that serves as a reminder that control instructions have been issued and further acknowledgement is (red) or is not (green) pending. o Serves as a backup to voice communication. o Should be used with Job Aid #4.	Recommended for testing.
13. MITRE's Ghosting display for spacing assistance to approach controllers	o The Ghosting display provides arrival controllers with a display aid that gives visual clues to enable them to conduct staggered approaches from 2 runways in IMC (Mundra, 1989).	Already being tested by FAA.
14. NASA - AMES Traffic Management Advisor for regulating traffic flow between centers and approach controls	o Traffic Management Advisor provides air traffic managers with an automated tool for scheduling traffic flows. Provides timelines and four interactive scheduling modes in a graphical interface (Erzberger and Nedell, 1989).	Already being tested by FAA.

TABLE 10. SUMMARY OF MEMORY AIDS AND RECOMMENDATIONS

MEMORY AIDS	WHAT CAN BE ACCOMPLISHED	RESULTS OF SCREENING
15. NASA - AMES Descent Advisor for descent assistance to center controllers	o Descent Advisor provides an automated tool for center controllers who manage descent of traffic. It generates information integrated into a plan view traffic display consisting of a high resolution color monitor. Provides estimated arrival times, graphical markers, computer-generated advisories and selection of horizontal guidance modes (Erzberger and Nedell, 1989).	Already being tested by FAA.
16. NASA - AMES Final Approach Spacing Tool for approach controllers	o Final Approach Spacing Tool provides an automated tool for approach controllers in TRACONs. Provides predictive trajectory information in a graphical interface, timeline display, speed/vector advisories, time error indicators and selection of horizontal guidance modes (Davis, Erzberger and Bergeron, 1989).	Already being tested by FAA.

SECTION 9.0 SUMMARY AND CONCLUSIONS

This report presents the results of the first year's efforts in a three-year project to identify, develop, test, and evaluate air traffic controller memory aids. The goals of the first year were to (1) develop an understanding of memory in controller performance, (2) identify controller memory problem areas, (3) identify potential memory aids, and (4) evaluate potential memory aids.

The first goal was accomplished by reviewing the available literature on air traffic controller memory and performance. These results were discussed in Section 3.0, and an included a definition of controller tactical working memory. We also developed a controller cognitive model (Section 4.0) which was based on a model developed by Rasmussen (1982, 1986) for operators of complex systems. The cognitive model was used to relate cognitive errors and memory components to operational errors (Section 5.0) and job aids (Section 6.0).

In section 5.0, we presented the results of our analysis of operational errors, using a classification scheme first used by Kinney et al. (1977). By relating operational errors to the controller cognitive model, we inferred memory errors and/or overload that contributes to operational errors, accomplishing the second goal. In section 6.0, we presented the results of our review of the available literature on the functions of job aids, and job aids specifically for air traffic control. Most of the ATC job aids discussed in section 6.0 are being developed and evaluated by the FAA and/or NASA. We also found that researchers have major concerns about the effects of proposed increases in automation on controller job satisfaction, performance and task structure. They stress that keeping controllers active and in the control loop is of primary importance in designing new ATC systems and will determine the acceptability and effectiveness of new systems.

Thus, we used subject matter expertise and the results of a limited inquiry on memory aids controller use today to develop additional ideas for potential memory aids. Some of the aids are based on informal procedures/techniques that controllers past and present have used as "memory joggers". Other ideas for aids were suggested by the literature which indicated a need to keep controllers active under all traffic loads and reduce reliance on automation to solve all control problems. The potential memory aids were presented in Section 7.0, including a discussion of memory/cognitive problem areas addressed. We also established qualitative criteria for evaluating potential memory aids. The criteria were based on discussions between the contractors and the COTR, with the objective of recommending some of the aids for testing in Year Two of this project. In Section 8.0, the results of our subjective evaluation were presented, concluding with recommendations for which memory aids should be tested in the second year.

Those memory aids recommended for testing include:

(1) CAN-Handoff check off blocks on flight progress strips

(2) the timesharing data block which includes last assigned altitude and heading, and an arrow indicating whether aircraft is climbing or descending; additional information for terminal controllers should include runway assignment and type of aircraft

(3) System Atlanta or other information management system.

(4) non-automated handoffs

(5) color coded flight strip holders for route direction

(6) enlarging strip bays to allow for offsetting strips

(7) use of color red to indicate warning or revision on flight strips

(8) a voice recognition system for detection of incorrect/incomplete call sign transmissions and for play backs of previous transmission

(9) standard format for placing and locating strips in strip bays

(10) challenge response checklist for position relief briefings.

Each of these memory aids addresses one or more memory/cognitive problem areas in one of two ways: (a) by providing controllers with a structure or procedure that enables them to prevent and/or detect errors, or (b) by providing storage and retrieval of information controllers would otherwise have to store in working memory or seek from other ATC personnel.

The major conclusion of this project is that reliability of air traffic controller memory recall is a significant problem affecting aviation safety and efficiency of the National

Airspace System operation. Identification of practical, effective memory aids is the first step towards the solution to this pervasive problem.

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