

ABSTRACT

MCCLERNON, CHRISTOPHER KYLE. Human performance effects of adaptive automation of various air traffic control information processing functions. (Under the direction of Dr. David B. Kaber.)

Advanced forms of automation are being considered for application to Air Traffic Control (ATC) in order to reduce controller workload and make higher traffic volumes more manageable. At this point in time there is only limited knowledge of the implications of, for example, Adaptive Automation (AA) on controller performance, workload, and Situation Awareness (SA). The purpose of this research was to (1) define a measure of SA in an ATC simulation that is a sensitive and reliable indicator of automation state changes as part of AA; (2) empirically assess the SA measure for use in investigating AA of various ATC information processing functions; and (3) determine the relationship(s) between AA in the ATC simulation and operator SA. The situation awareness global assessment technique (SAGAT) was considered to be an appropriate candidate measure of SA during AA of an ATC simulation.

An experiment designed to empirically assess the sensitivity of a SAGAT-based approach included an ATC simulation, Multitask©, which is capable of simulating five forms of ATC information processing automation: manual control (no automation), information acquisition, information analysis, decision making, and action implementation. A secondary, signal detection-based gauge-monitoring task was used to measure Multitask© workload and trigger dynamic function allocations (DFA) between manual and automated control. Eight subjects were recruited for the study and each performed under the five modes of automation twice (one repetition). Performance measures were collected for both the Multitask©

simulation (aircraft cleared, conflicts, and collisions) and the gauge-monitoring task (workload).

The SAGAT involved freezing the simulation three times per trial and querying the subjects on their perception, comprehension, and projection (Level 1, 2, and 3 SA) of simulation states. Subject responses were scored based on “ground truth” observations recorded during stops. Data was analyzed, first, on a per stop-basis in order to identify any effect of the general type of control (manual or automated), and then on a per trial-basis to identify any mode of automation effects.

Results revealed that AA of the action implementation aspect of ATC information processing produced superior performance during the automated control periods as part of the simulation. In addition, automation of the information analysis aspect of ATC information processing appeared to have a positive effect on performance during manual control periods as part of adaptive conditions. Subjects were able to benefit from the automation even during periods of manual control of the simulation. Counter to expectations, no significant findings were revealed for secondary task performance (workload). Situation awareness results revealed that subjects were better able to project the future simulation status (Level 3 SA) during manual control periods of the simulation than when operating under automation. The SAGAT data analysis revealed no significant effect of the specific mode of automation on SA. In general, these results suggest that SAGAT was not a sensitive measure of SA in the simulated ATC task. This was primarily attributed to a lack of consideration of the relevance of particular aircraft to a controller, at any given point in time in the simulation, as part of measurement technique. As a result, the final objective of determining relationship(s) between AA in ATC and controller SA was not achieved.

The performance results of this study were in agreement with the results of prior research demonstrating ATC information processing to benefit most from lower-order automation, like action (clearance) automation. The study also further demonstrated the use of a secondary-task measure of workload as a basis for facilitating AA in a complex task.. With respect to SA, the study exposed a need for future research to assess the sensitivity and reliability of SAGAT in an ATC environment and the potential for development of a more sensitive SAGAT-based measure for this domain that considers issues of aircraft relevance and concurrent controller goal sets.

**HUMAN PERFORMANCE EFFECTS OF ADAPTIVE AUTOMATION OF
VARIOUS AIR TRAFFIC CONTROL INFORMATION PROCESSING FUNCTIONS**

by
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Biography

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List of Abbreviations

AA	Adaptive Automation
AFB	Air Force Base
ANOVA	Analysis of Variance
ARTS	Automated Radar Terminal System
ATC	Air Traffic Control
CA	Conflict Alert
CAA	Clearance Advisory Aids
CDA	Conflict Detection Aids
CRDA	Converging Runway Display Aid
CTAS	Center TRACON Automation System
DA	Descent Advisor
DFA	Dynamic Function Allocation
DL	Data Links
EDD	Electronic Data Display
EDP	Expedite Departure Path
FA	Function Allocation
FAA	Federal Aviation Administration
FAST	Final Approach Spacing Tool
FDP	Flight Data Processing
FMS	Flight Management System

FSL	Full Service Level
GDTA	Goal Directed Task Analysis
GPWS	Ground Proximity Warning System
HIP	Human Information Processing
HTA	Hierarchical Task Analysis
IE	Industrial Engineering
IFR	Instrument Flight Rules
IV	Independent Variable
LOA	Level of Automation
MSAW	Minimum Safe Altitude Warning
NC	North Carolina
NCSU	North Carolina State University
NRC	National Research Council
OOTL	Out-of-the-loop
OOTLUF	Out-of-the-loop Unfamiliarity
PRAT	Prediction/Resolution Advisory Tool
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SD	Standard Deviation
SI-SFO	Straight-in Simulated Flame-out
STARS	Standard Terminal Automation Replacement System
TCAS	Traffic Alert and Collision Avoidance System
TMA	Traffic Management Advisor

TPA	Trajectory Projection Aid
TRACON	Terminal Radar Approach Control
URET	User Request Evaluation Tool
USAF	United States Air Force

1 Introduction

Air traffic control (ATC) is one of the most complex and stressful jobs in the world. Controllers are responsible for communicating with numerous aircraft simultaneously, while constructing complex three-dimensional mental “pictures” of the airspace environment in their minds and maintaining strictly regulated aircraft separations and procedures. The consequences for mistakes include costly delays and possible injuries or death; consequently, the margin for error is minimal. Beyond this, airspace is becoming increasingly congested (Hopkin, 1999). One method currently employed to alleviate task burdens placed on air traffic controllers is the introduction of computer control, or *automation*, in aircraft information processing.

There are currently many different forms of automation incorporated in ATC, and they can have many advantages for air traffic controllers including a reduction in workload (Laois & Giannacourou, 1995), an increase in system reliability (National Research Council (NRC), 1998), and the capability to perform complex computations and data management (Wickens & Hollands, 2000). However, automation in ATC can also present many disadvantages (Dillingham, 1998), including the removal of the human from the control loop (Wickens, 1992; Parasuraman, Sheridan, & Wickens, 2000; Sanders & McCormick, 1993; Endsley, 1996; Endsley & Kaber, 1999), vigilance decrements (NRC, 1997), and complacency (Parasuraman & Riley, 1997; Endsley, 1993; Laois & Giannacourou, 1995; Parasuraman et al., 2000).

The implementation of automation in ATC may also compromise a controller’s ability to maintain situation awareness (SA); or the perception of elements in the

environment, the comprehension of their meaning, and the projection of their future status (Endsley, 1995a). Situation awareness has been found to be a critical factor in successful ATC, and must be addressed when designing automated systems for ATC (Endsley & Jones, 1995; Endsley & Rodgers, 1994). New, advanced forms of automation are being considered for ATC to alleviate the disadvantages of conventional automation, and to preserve operator SA. These advanced forms of automation involve providing computer assistance only when assistance is needed by a controller, or adaptively applying automation to ATC information processing functions.

The following sections define SA, discuss the importance of SA in ATC, describe the role of automated systems in ATC, and address the impact automation can have on human performance, including SA in an ATC environment.

1.1 Situation Awareness in Air Traffic Control

In March, 1994, a United States Air Force (USAF) F-16 approached Pope Air Force Base (AFB), North Carolina (NC) with ATC clearance, attempting a straight-in simulated flame-out (SI-SFO) approach – a high-speed final approach with a very high approach angle. The air traffic controller did not notify the F-16 of a C-130 in the pattern, because he intended to simply sequence the C-130 behind the F-16. However, the controller used the wrong call sign in sequencing the aircraft, resulting in the C-130 continuing on its approach in front of the F-16. With the F-16 converging very steep and fast behind the C-130, the controller called “Cargo traffic short final on the go,” to alert the F-16 of the C-130’s close proximity. The controller assumed the F-16 could clearly see the traffic, but the steep approach angle placed the large cargo aircraft below the fighter’s field of view. Soon after

the controller's radio call, the F-16 was cleared to land, and the two aircraft collided. The two F-16 pilots ejected safely, but the aircraft impacted a Pope AFB staging area killing twenty-four Army personnel and injuring more than 100 soldiers and civilians on the ground. The C-130 landed safely with significant damage (Alkov, 1997).

This accident provides an example of insufficient air traffic controller SA resulting from increased workload in a busy and complex airport traffic pattern. (This will be expanded on below in defining the concept of SA.) At the time of this accident, Pope AFB was the home to a composite air wing; that is, the base operated many different types of aircraft, all with different missions, from the same airfield. The disparity in aircraft performance parameters increased the cognitive load placed on controllers because of the requirement to recall different aircraft capabilities and to coordinate them on this basis. The NRC (1998) has found that decrements in SA may occur due to factors, including high stress and workload, and this may increase the likelihood of ATC errors. The Pope AFB accident was found to be the result of inadequate controller guidance, training, and experience resulting in insufficient controller SA (Alkov, 1997).

Unfortunately, with the volume and diversity of traffic at many of the US airport's surpassing capacity within the last five years (Donohue, 2001), incidents like this are becoming more likely in both the military and civilian sectors. The workload and complexity of ATC may ultimately result in decreased levels of air traffic controller SA, which the NRC (1998, p. 25) has found to be an underlying factor in complex system operator performance and errors. Other research has further described SA and how it is critical to ATC. This work is reviewed here.

Defining Situation Awareness

Endsley (1995a) defines SA as the “perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1995a, p. 36). In the context of ATC, SA has also been described in many instances as a *picture* of the environment that a controller must maintain internally (Niessen et al., 1999). The three elements of Endsley’s (1995a) definition delineate three different levels of SA:

- Level 1: Perception of elements in the environment,
- Level 2: Comprehension of the current situation, and
- Level 3: Projection of future status (Endsley, 1995a).

In regard to ATC, Level 1 SA is considered to be perception of critical information relating to each aircraft and the environment within a controller’s airspace. For example, heading, altitude, and airspeed of controlled aircraft; the status of each aircraft, including fuel on-board, emergencies, etc.; and airport and airspace information including active runway(s) and airspace restrictions.

Level 2 SA is considered to be information consciously abstracted from the environment, based on operator knowledge of a system (Level 1 SA) and the system goals (e.g., in ATC, assuring flight safety; Endsley & Rodgers, 1994). For example, what are the aircraft’s flight parameters based on its type (i.e., speed, range, weight, etc.); what is the aircraft’s proximity to destinations, other aircraft, and ground terrain based on its current coordinates; and what is the runway availability considering airborne and ground-based activity.

Level 3 SA is the prediction of future aircraft status based on current Level 1 and Level 2 SA. Specific air traffic controller predictions might include future aircraft heading, altitude, and airspeed; future aircraft conflicts; and future proximity with other obstacles. As can be discerned from this description of SA, the levels of SA are hierarchical in that they build on each other. If Level 1 SA is not achieved, it is unlikely that either Level 2 or Level 3 SA will be achieved. It is important to note that SA is often referred to as a *snapshot* of operator cognition in time, meaning an operator's situation model is relevant for a particular place and time (Endsley, 1995a).

In the Pope AFB accident described above, the controller committed a Level 1 error by perceiving the wrong information on the C-130, and calling the aircraft the wrong call sign. Insufficient training and experience also contributed to the commission of a Level 2 SA error by preventing the controller from accurately determining the F-16's speed and descent rate based on the knowledge that the F-16 was performing an SI-SFO. Finally, assuming the flight parameters for both aircraft were known, the controller failed to accurately predict their future locations, a Level 3 SA error, which prevented the controller from predicting the intersecting courses. Here it can also be observed that because of the hierarchical properties of the levels of SA, once a lapse in Level 1 and Level 2 SA occurred, a Level 3 error became likely.

Another concept presented by Endsley (1993) that is relevant to this research is the notion that SA and workload may vary independently. Endsley (1993) demonstrated that, depending on the task and operator goals, SA may decrease as workload increases because of the demand on attentional resources and task saturation, provoking incomplete SA. She also observed that SA may decrease as a result of low workload and complacency. Likewise, SA

may improve when optimal workload levels are prescribed for a task, which provokes optimal arousal and performance (Wickens, 1992). Relating to ATC, if a controller's workload increases as a result of controlling multiple aircraft of different types, requiring numerous communications and actions, then SA can drastically decrease as in the case at Pope AFB. However, a decreased workload resulting from minimal traffic may also lead to controller boredom, complacency and degraded SA.

With respect to the relation of SA and performance, it is likely that SA has a direct impact on ATC functioning (Endsley & Kiris, 1995). However, as Endsley (1995a) pointed-out, SA does not guarantee good performance, but it is “a factor that will increase the probability of good performance” (Endsley, 1995a, p. 40).

Wickens (2002) also breaks SA down into three components and identifies the aspects and features of aviation systems that are most relevant to each component. Wickens' (2002) components include: spatial awareness, system awareness, and task awareness. Three-dimensional spatial awareness in an ATC context is the awareness of all aircraft locations and orientations within the controlled area. Each of these parameters are dynamic and have an effect on the others. For example, if an aircraft's orientation is changed (e.g., it pitches nose-down) then the future location of that aircraft will change as well (i.e., it will likely be lower) and it may have new flight parameters (e.g., a possible increase in airspeed). There may also be unpredictable time lags between these variables, increasing their complexity.

The second component of SA, system awareness (or mode awareness), is knowing the status of the stimuli in the environment, or being aware of the flight status of each aircraft. Wickens (2002) clarifies this by saying, “people remember actions that they themselves have

initiated better than those initiated by another agent” (p. 131). In the Pope AFB example, the C-130 continued to final approach without direction from the controller, because the controller used the wrong call sign. As a result of the controller not initiating correct actions, the controller lost awareness about the C-130’s location and intentions. Automation can have a significant impact on system awareness, because the more a controller is removed from the control loop the less system awareness is retained (Wickens, 2002).

Finally, Wickens (2002) defines task awareness as knowing what tasks are required to achieve the overarching goal and the order in which to address the tasks. Knowledge of a system’s goals allows an operator to respond to a situation quickly and efficiently even if an operator has not obtained sufficient SA. For example, an air traffic controller may not be consciously thinking about the fact that there is a general aviation aircraft traversing a tower controlled airspace without the intent to land, but as another aircraft approaches the airport to land, the controller’s goal of aircraft separation causes the controller to quickly and accurately separate the two vehicles.

Like Wickens (2002), Niessen et al. (1999) state that there are three requirements for the ATC picture, or controller SA, including:

- (1) a cyclical update of varying relations between aircraft and the environment as a basis for SA;
- (2) the prediction of the future states in order to detect risky relationships between aircraft; and
- (3) the determination of the temporal sequence of cognitive activities in meeting simultaneous task requirements (Niessen et al., 1999).

Niessen et al. (1999) also presented a model that depicted the different phases of controller information processing required for SA, including data selection, anticipation, conflict resolution, update and control. These five steps contribute to the mental picture developed by the controller. In addition, according to Niessen et al. (1999) these steps do not occur in parallel, but, rather, must be performed separately. Experience also plays a large roll in the use of this model, as experienced operators “use less information, but that this information is diagnostically more relevant” (Niessen et al., 1999, p. 1513).

Situation Awareness and Other Cognitive Constructs

There are many cognitive constructs that have been hypothesized to have relationships with SA and that may be essential to complex system operator achievement of SA, including attention, perception, and memory. Attention, as discussed by Endsley (1995a), is a critical factor in developing SA and is needed for perception, information storage, decision making, and response execution functions as part of human information processing (HIP). Attention is required to filter information in an environment that is essential for the development of SA from other distracter information. Attentional mechanisms are used in identifying elements in the environment that are familiar, or represent habituated stimuli (Cowan, 1988), compared to novel stimuli that may require further processing. This filtering of information allows complex system operators to manage large amounts of data in the environment. For example, it may be critical to air traffic controllers in achieving SA even when many different aircraft are operating within their airspace.

Perception is another cognitive construct that is considered essential for achieving SA (within ATC). Endsley (1995a) states that working memory is the primary aspect of cognition used in recognition/classification of stimuli in an environment. Working memory also serves as a dynamic storage for concurrent operator task goals. The air traffic controller compares his or her current goals with perceived information in order to comprehend current traffic situations (Level 2 SA). In addition, perception of stimuli within the environment (facilitated by recognition and classification through working memory) leads to the development of an internal situation model that is matched to mental models in long-term memory. This process forms the basis for decision making and projection of future states of a system (Level 3 SA).

Long-term memory is related to SA in that situation models may be used to enhance and expand existing mental models. This may allow, for example, expert controllers to effectively sort information and determine which stimuli are most important at a particular moment. Therefore, the controller can achieve adequate SA in a stimulus-saturated environment. This suggests a circular relationship of situation models and mental models. Long-term memory can also effect the efficiency (i.e., speed and accuracy) of perceiving information in the environment (Level 1 SA). Expert controller's expectations and preconceptions about task information based on long-term memories (mental models) allow accurate Level 1 SA to be achieved through timely aircraft and environmental perception. (Endsley, 1995a)

Identifying Goals and Tasks for Air Traffic Control

Endsley and Rodgers (1994) and Endsley and Jones (1995) conducted research to determine the goals and tasks for ATC, as well as controller SA requirements, and the information required to accomplish ATC goals by using Goal Directed Task Analysis (GDTA). Endsley and Rodgers (1994) interviewed retired air traffic controllers and analyzed simulated ATC scenarios to develop a very extensive list of SA requirements for en route controllers. *En route* ATC refers to the control centers across the country responsible for separating, navigating, and handing-off aircraft between airport, or *terminal*, air space (Nolan, 1999). These en route requirements consist of overarching ATC goals. Secondly, subgoals are defined which are required for accomplishing the goals. Subsequently, questions that must be answered by the controller to accomplish subgoals are developed. These questions can later be used to assess SA in the task, and will be discussed in a later section of this document. Finally, the high-level and low-level SA requirements for answering questions are outlined.

Endsley and Jones (1995) performed a similar analysis to evaluate the SA requirements for Terminal Radar Approach Control (TRACON) centers. A TRACON area refers to the controlled airspace within the immediate vicinity of a congested airport (Nolan, 1999). A portion of one GDTA conducted by Endsley and Jones (1995) for avoiding aircraft conflicts during TRACON operations (i.e., separate aircraft) is presented here with labels differentiating the various elements of the GDTA:

[goal]	1.1 Separate aircraft
[subgoal]	1.1.1 Assess aircraft separation
[question]	- vertical separation meets or exceeds limits?
[high-level SA information]	-- vertical distance between aircraft along route (projected)
[high-level SA information]	-- vertical distance between aircraft (current)
[low-level SA information]	-- aircraft altitude (current)
[low-level SA information]	-- altitude accuracy
[low-level SA information]	-- altitude (assignment)
[low-level SA information]	-- altitude rate of change (climbing/descending)

(Endsley & Jones, 1995, p. 19)

This type of analysis is an important tool for understanding ATC SA requirements, and is valuable for designing and developing future ATC systems by considering controller information needs.

Situation Awareness and Air Traffic Control Performance and Automation

All definitions of SA agree that the mental construct has a critical impact on human performance, particularly in a complex system like ATC. Air traffic control is a very unique and demanding occupation in terms of the magnitude of information presented in multiple mediums, the requirements to make timely decisions, and the importance of correct decisions. It is imperative in ensuring flight safety that air traffic controllers are assigned appropriate levels of workload and achieve adequate levels of SA. In the Pope AFB incident, the controller had relatively high levels of workload and insufficient SA due to inadequate experience and training, resulting in performance decrements (e.g., forgetting call signs and incorrect clearances).

One method explored to alleviate stress and workload on controllers is the use of automation in ATC. In the following sections, definitions and forms of automation are provided in addition to potential advantages and disadvantages of using automation within ATC.

1.2 Automation in Air Traffic Control

With the increase in aircraft volume and the types of aircraft being flown in airspaces around the world, actions must be taken in order to help controllers to manage the inevitable airspace congestions while maintaining safety, efficiency, and reducing costs (NRC, 1998). One common strategy for relieving controller stress is partitioning, or reducing the airspace an individual controller is responsible for. However, according to Hopkin (1999) partitioning has reached its maximum obtainable benefits as the airspace becomes so small that a controller is responsible for more frequent hand-offs of aircraft to other controllers, more communications, and increased coordination; thus, further increasing workload and possibly decreasing SA. As technology provides more capabilities to ATC, a more feasible solution to remedy increased airspace congestion is to allocate some of the controller's responsibilities to computers, or *automation*.

Defining Automation

Automation has been defined as, “the execution by a machine agent of a function previously carried out by a human” (Parasuraman & Riley, 1997, p. 231). Furthermore, the NRC (1997) expands this definition by including either partial or full automation of a function that was previously (partially or fully) accomplished by a human. Hopkin (1999)

defines system functions that are fully automated as, “functions that do not require, and often do not permit, any direct human participation or intervention in them” (p. 498). Billings (1997) further describes automation as a tool that allows a human operator to accomplish a task with less effort, or to complete a task that would have been impossible otherwise.

Air traffic control automation first appeared in the 1960’s in the form of the Automated Radar Terminal System (ARTS), which incorporated all aircraft information within one controlled space into one radar display. Modern versions of the ARTS are still in place today. Since the 1960’s, many new applications have been developed for automation integration. These will be discussed in the following sections.

Identifying Forms of Automation

Wickens (1992, p. 531-532), in attempting to define different types of automation, identified three general circumstances in which automation can be employed. First, automation can be used to perform functions that the human operator cannot perform because of inherent limitations. For example, humans are generally limited in their ability to “monitor for prespecified events, store and retrieve coded information, and perform repetitive activities reliably” (Sanders & McCormick, 1993, p. 730-731). These are activities which computers are particularly apt at performing (Wickens & Hollands, 2000). Examples of this form of automation in ATC include flight data processing (FDP) for en route centers where information about flights and controller interactions is stored in a database for later data synthesis, data presentation, and computations to be used for performance evaluation and training. These are all processes that humans perform poorly compared to computers (Wickens & Hollands, 2000). Another example of this form of automation is smoothing of

aircraft flight information on ATC displays. Flight data regarding specific aircraft is gathered incrementally and presented to controllers on displays, but this unprocessed information presents jagged, irregular display movements, which can be distracting to controllers without the aid of an automated process called *smoothing* that extrapolates the flight data into smooth, fluid movements of the aircraft displays (NRC, 1997).

Wickens (1992) also describes automation used to perform functions that humans perform poorly or at the cost of high workload. As previously mentioned, as airspace becomes more congested, and partitioning decreases the sizes of airspace, controllers are required to perform the taxing process of handing-off aircraft to other controllers more frequently. Automated systems have been implemented to handle hand-offs, thereby eliminating the need for verbal communication between controllers as aircraft pass through airspace, and decreasing both controller and pilot workload. In addition, controllers were previously required to obtain aircraft altitude, speed, and other information verbally from pilots for hand-offs. They were also expected to perform the complex process of determining specific aircraft headings based on limited and inaccurate aircraft information presented on controller displays. This information including aircraft call sign, type of aircraft, destination airport, navigational fixes, altitude, and ground speed are all now automatically presented to the controller in an accurate data tag embedded in the radar display (NRC, 1997).

Automation is also used to augment or assist humans in areas they show performance limitations (Wickens, 1992). In an effort to aid controllers with automation, the Federal Aviation Administration (FAA) introduced the center-TRACON automation system (CTAS). This system assists controllers in successfully clearing aircraft, rather than implementing fully automated systems (Dillingham, 1998). Other ATC automation systems utilized to

assist controllers are the Minimum Safe Altitude Warning (MSAW) system, the Conflict Alert (CA) system, and the automated (aircraft) track deviation system (NRC, 1997). In addition, controller requirements to maintain aircraft separation from other aircraft and the ground has been augmented by various forms of cockpit automation systems including the Traffic Alert and Collision Avoidance System (TCAS) and the Ground Proximity Warning System (GPWS). These systems alleviate controller workload by allocating some separation responsibilities to pilots (NRC, 1997; Nolan, 1999).

Advantages and Disadvantages of Automation

Automation can have a profound effect on human performance. Automation has many advantages and, with the availability of modern technology, has become a viable option for reducing the load on air traffic controllers, increasing ATC efficiency and safety, and decreasing cost. However, when improperly implemented, there are also many potential disadvantages of using automation.

Workload

One of the primary goals of incorporating automation into a system is often to decrease workload. Laois and Giannacourou (1995) conducted research to determine the impact of five currently automated ATC systems, including: Electronic Data Display (EDD), Trajectory Prediction Aids (TPA), Conflict Detection Aids (CDA), Data Links Applications (DL), and Clearance Advisory Aids (CAA). Their study consisted of observations, interviews, and presenting expert controllers with questionnaires pertaining to the automated systems. They determined that all five forms of automation increased formalization (of

communication), performance, and flexibility while decreasing workload by assuming responsibility for ATC functions. They also determined that “significant workload reductions will be effected by aiding decision making and predictive activities and not by automation of routine data acquisition and communication activities” (Laois & Giannacourou, 1995, p. 395).

However, introducing automation does not always decrease workload; in some cases, automation may actually increase workload. Parasuraman and Byrne (2002) suggest three situations where improper automation may increase operator workload. First, if automation requires extensive reprogramming or data entry during critical events, then the automation may actually increase workload (e.g., if a controller is required to input data into a system during a close proximity warning). Second, if the nature of the automated system requires the user to continuously evaluate the benefit of automation compared to manual control (as in adaptively automated systems), the system may induce higher workload. This is important in the implementation of adaptively automated systems (Clamann & Kaber, in press). Finally, if the results of automation are so critical or unreliable that the automation performance must be continually evaluated for errors, user workload may increase. This is a critical issue for ATC automation, because ATC errors can be catastrophic. Riley (1996) found that in situations where automation significantly increased workload, given the choice, operators often chose to operate manually.

System Trust

Operator trust in an automated system is another important automation factor in ATC that is affected by the design and performance of automation (Wickens, 2000). The NRC

(1998) presented seven characteristics that determine trust in an automated system: reliability, robustness, familiarity, understandability, explication of intentions, usefulness, and dependence. Any or all of these factors can contribute to one of many resulting scenarios: overtrust, mistrust, and any level of trust between the two (Parasuraman & Riley, 1997). The primary factor influencing overtrust is automation reliability (Wickens, 2000; Parasuraman & Byrne, 2002). If a system appears to be extremely reliable, and errors are very rare, then the operator will place a great degree of trust in the system (Parasuraman & Riley, 1997). However, perfect automation performance is rare, and too much trust also fosters complacency, which, as Endsley (1993) noted, can decrease SA and make system recovery from errors much more difficult.

Lower or variable levels of system reliability can be used to overcome overtrust problems (Parasuraman et al., 2000), but a very low level of reliability can lead to mistrust. Mistrust often leads to operators refraining from use of the automation or ignoring it. Mistrust has also been attributed to an unreliable system with a high level of false alarms (Parasuraman & Riley, 1997; Wickens, 2000). In a system like ATC, errors have great consequences (e.g., aircraft accidents may result in fatalities, aircraft damage is very expensive, and delays are very costly). Therefore, system designs often aim to decrease the likelihood of a missed error, at the cost of increasing the probability of a false alarm (Wickens, 1992). In addition to false alarms, a lack of understandability of automation may also lead to mistrust (Endsley, 1996). The aircraft Flight Management System (FMS), a cockpit computer which aids pilots in aircraft navigation and communication, and the Standard Terminal Automation Replacement System (STARS), a terminal system that is currently being employed by ATC to integrate aircraft hand-off, communication, radar,

weather, and air traffic data, are both very complex systems (Nolan, 1999). With an incomplete understanding of all of their various modes and behaviors, pilots and controllers may not trust their capabilities. Automation design and training is responsible for making complex automation systems transparent and understandable in order to decrease mistrust.

Out-of-the-Loop Unfamiliarity

Another possible drawback of implementing automation is reducing the level of operator interaction with the system and reducing familiarity, which Wickens (1992) defines as “out-of-the-loop unfamiliarity” (OOTLUF). As more ATC functions and operations are performed by machines, controllers have less interaction with the system and may become less aware of system operations. Parasuraman, Sheridan, and Wickens (2000) point out that automation may change the role of humans from system controllers to supervisors monitoring system status, a function to which humans are not well suited (Endsley, 1995b). Out-of-the-loop (OOTL) performance may reduce a controller’s ability to detect that a problem has occurred, determine the current state of the system, understand what has happened and what courses of actions are needed (develop SA), and react to the situation (Endsley, 1996).

Endsley and Kaber (1999) identified five consequences when implementing automation in a manner that places the controller OOTL, including: difficulty in assuming control when needed, vigilance decrements, complacency (discussed previously), skill decay, and loss of SA. With respect to the first consequence associated with implementing automation, an operator may be removed from a control loop to the extent that in the event of an emergency or automation failure, the controller may not be able to regain manual control.

Laois and Giannacourou (1995) observed this in their study of expert controllers when they found that automation which places the controller OOTL can result in the inability to react to an emergency situation.

Vigilance decrements are the result of extended periods of monitoring, which decrease operator sensitivity to task stimuli, so that the ability of the user to discriminate, recognize, and diagnose critical events is compromised (NRC, 1997), and the accuracy and speed of these responses can be severely affected. An ATC example of potential vigilance decrements can be found during the infrequent, yet critical, instance that a data tag on a radar display is inaccurate. A controller is always monitoring data for accuracy, but when the controller is removed from the active process of gathering aircraft data, and this information is presented automatically, a vigilance decrement can occur resulting in issuance of a wrong clearance or a clearance to the wrong aircraft because of inaccurate data. Sufficient controller breaks and active involvement in system control during low workload periods may decrease the likelihood of vigilance decrements (NRC, 1997).

Complacency, as discussed earlier, is a function of trust within a system, reliance on the automation, and confidence in the automation. Trust in automation is critical for effective system monitoring, but too much trust can result in complacency, leading to errors and missed critical events (Parasuraman & Riley, 1997). Endsley (1993) suggested that low levels of workload can also induce complacency, and that complacency can negatively affect SA, making the operator less aware of system status.

Complacency is a difficult issue to remedy when operators are removed from a system control loop (Laois & Giannacourou, 1995). Parasuraman et al. (2000) found that if automated system reliability was variable, alternating between high and low levels, then

operator trust in the system also became variable, decreasing complacency. Salient warnings and alarms, and providing information regarding system status may also reduce complacency and stimulate operator attention by alerting them to system failures (Parasuraman & Riley, 1997; NRC, 1998). Another method for overcoming complacency issues is the use of more advanced forms of automation, discussed in Section 1.3.

If controllers work OOTL for extended periods of time, or automated systems are highly reliable and evoke high levels of operator trust, controller skills may degrade (NRC, 1999). This drawback of automation is known as *skill decay* (Endsley & Kaber, 1999). In the automation of most systems, skill decay is inevitable as an operator becomes less actively involved in control. For example, in a highly automated system like CTAS or STARS, controllers are likely to lose the skills required to perform basic ATC functions such as flight tracking or ground and aircraft close proximity detection (NRC, 1998). This becomes problematic when a situation requires a controller to revert to manual control, as discussed earlier. Recurring training, periods of manual control, and thoughtful automated system design are important for maintaining controller skills (NRC, 1998).

Situation Awareness

Automation can have a profound effect on SA. As discussed earlier, automation may remove the operator from the role of active system controller to the role of monitoring, or supervisory controller. Although this may decrease workload (or increase it in some situations), the operator may lose the ability to perceive, comprehend, or project the future status of the system within the operating environment, or a loss of SA (Wickens, 2002). Endsley (1996) identified SA as the most challenging aspect of monitoring within an

automated system, and she said that maintaining SA is vital for proper decision making and performance. She also states that partly or fully automated tasks can decrease operator SA compared to fully manual control, because having a passive role in the system's performance prevents the user from understanding its current and future status. Furthermore, "turning a human operator from a performer into an observer can, in and of itself, negatively affect SA" (Endsley, 1996, p. 3). These SA deficiencies become apparent when a supervisory controller is required to initiate and maintain manual control of a system in response to an automation failure. Automation of different levels of HIP can also affect SA in different ways. Endsley and Kiris (1995) and Kaber, Onal, and Endsley (1999) determined that low-level automation can improve SA, while high-level automation like decision-making aids can decrease SA.

Examples of ATC automation leading to decrements in controller SA can be found in the many different types of mode errors that occur with automated ATC systems. A mode refers to "the setting of a system in which inputs to the system result in outputs specific to that mode but not to other modes" (Parasuraman & Byrne, 2002, p. 328). Mode errors result when an operator, because of high levels of automation and multiple system modes, is unaware of the mode in which a system is currently operating; thus, the controller inputs data, or extrapolates data from a system, assuming the wrong system mode is active. High level automation can decrease SA and the operator becomes unaware of mode changes and activities prior to interacting with the system. Many aircraft accidents have resulted from low levels of SA and mode errors, particularly with the aircraft FMS, because the pilot was OOTL (Parasuraman & Byrne, 2002; NRC, 1997).

All of these problems can be attributed to operators performing tasks while OOTL. However, there are aspects of automation design that can be manipulated to maintain

operator SA by maintaining in-the-loop performance. One aspect of system automation critical to SA is appropriate feedback. Proper feedback about a system's status can improve controller SA (Endsley, 1996), improve OOTL performance, and improve safety in automated systems (Parasuraman & Byrne, 2002). In the example of mode errors, proper feedback about the current system mode changes can improve operator SA and decrease OOTL errors. In addition, Parasuraman and Byrne (2002) suggest that automated states and behaviors be salient and understandable for better automated performance. This includes warnings and signals about the system status (e.g., feedback) being obvious and clear in their meaning.

Summary

Air traffic control automated systems are not perfect. Although their intention is to alleviate workload placed on controllers and improve system performance, unfortunately the manner in which automated systems have been designed and implemented has sometimes led to the opposite. There are other automation methods that focus on the design and integration of modern technologies with human control. As research and development make these forms of automation more accessible and exposes the advantages of using new methods, they may become actual approaches for overcoming some of the disadvantages of existing automation.

1.3 Advanced Automation in Air Traffic Control

The drawbacks of automation, which have been discussed, are primarily relevant to systems that operate under either full automation or forms of supervisory control. However, Hopkin (1998) suggests four broad forms of automation that can be used in ATC systems,

some of which extend beyond the previously discussed forms of traditional automation, including:

- human tasks that can be automated completely so the human retains no role in them;
- human tasks that can be performed with various forms of computer assistance so that they may be simplified, reduced in procedure, reduced in detail or frequency, or permit the controller to act more quickly;
- human tasks that can be divided, leaving some parts for the human to perform while other parts are performed automatically; and
- human roles that can be changed from tactical interventions during flights of single aircraft to strategic preplanning of traffic flows.

Full Automation

The first form of automation represents traditional technology-centered automation and is typical of early automated systems. The Full Service Level (FSL) is a feature of STARS that fully automates the ATC data gathering process. Radar, flight plan, and weather information was once collected manually by controllers, one element at a time, and the controller was required to integrate this information for proper aircraft clearance. The FSL automatically integrates aircraft radar images, flight plans, and pertinent weather information and presents it to the controller in an easy to discern display (NRC, 1998). However, this type of data gathering automation may remove the controller from the control loop, and result in negative automation consequences.

Computer Assistance

The CTAS is a good example of an ATC automated system which provides automation assistance for controllers. The CTAS has four components, the first being the Traffic Management Advisor (TMA). This computer system gathers information about all of the aircraft inbound for a landing, and uses the aircraft parameters to develop a plan including a sequence and schedule for landing all of the aircraft. This plan may be accepted or adjusted by the controller to meet specific requirements not considered by the automated system (e.g., emergency procedures, special requests, etc.; NRC, 1998). Secondly, the CTAS system incorporates a Descent Advisor (DA) which uses aircraft type, capabilities, atmospheric conditions, and a plan from the TMA to advise controllers about decent rates, speeds, and durations for each aircraft (Hilburn, Jorna, Byrne, & Parasuraman, 1997). Lastly, the Final Approach Spacing Tool (FAST) provides controllers with aircraft sequence, runway assignments, speed, and heading advisories. The final approach portion of a flight is the most crucial segment given the close proximity of aircraft near an airport, limited time to make decisions, and the precision and safety requirements of decisions (NRC, 1997). The FAST has the capability to quickly and precisely adjust to dynamic situations during the final approach segment. The DA and FAST advisories are presented automatically to the controller through the aircraft data tags on the radar display. The Expedite Departure Path (EDP) program is a recent addition to the CTAS which incorporates the same capabilities of the FAST and DA, but for directing aircraft that are departing a controlled area. In addition, these capabilities are becoming available not only for the aircraft arriving and departing the controlled airport, but for aircraft arriving and departing smaller airports within close proximity to the controlled airport (NRC, 1998; Nolan, 1999).

Function Allocation

Hopkin (1998) also suggests dividing ATC tasks between human and computer controllers as a method for effective automation. Sanders and McCormick (1993) define this approach to automation as function allocation (FA). The primary dilemma when applying FA to an automated system, is deciding which functions should be automated and which functions should be performed manually by the operator. In general, Kaber and Endsley (1997) determined that “in dynamic, multi-task environments some human manual performance is useful to overall system functioning” (p. 209), and that shared human and automated control of a system is often better than fully automated control. Studies have investigated the allocation of automated assistance to the various stages of human-machine system information processing in dynamic control tasks to determine which forms of automation are most advantageous for supporting human performance (Kaber & Endsley, 1997; Parasuraman et al., 2000; Clamann, Wright, & Kaber, 2002). Kaber and Endsley (1997) defined 10 different forms, or levels, of automation (LOAs) ranging from manual control to full automation by developing FA schemes for humans and machines in dynamic control tasks. Their empirical research determined that the LOA has a significant effect on radar monitoring and target elimination task performance. Specifically, they found that FA of lower forms of automation, like action support, as opposed to higher LOAs, like decision-making, resulted in superior performance even when compared to full automation. Likewise, Laois and Giannacourou (1995) stated that automation tends to have a more beneficial effect on low-level HIP functions in complex systems, like information acquisition and communication, and less of an effect on higher-level processes, like diagnosis, prediction and decision making. Similar to Laois and Giannacourou (1995), Endsley and Kaber (1999)

found that automation of task planning and strategizing functions degrades dynamic control task performance compared to purely human strategizing.

Level of automation can also refer to the amount of computer assistance provided to an operator on a particular system function. Parasuraman et al. (2000) defined LOA as the amount of computer assistance that is applied to a particular information processing function, varying from the lowest level of automation, or manual control, to the highest level of automation, or full automation. They also identified four different types of automation, based on Wickens' (1992) stages of HIP, including information acquisition, information analysis, decision selection, and action implementation. Each type of automation can occur at varying levels.

This particular model of automation has many implications for ATC. For example, Parasuraman et al. (2000) suggest that high levels of information acquisition and information analysis should only be incorporated into a system that has been proven to be very reliable. They offer the converging runway display aid (CRDA) as an example of a reliable automated ATC system. The CRDA projects the future paths of two aircraft landing on converging runways, relieving the controller of having to mentally project the aircraft paths. Likewise, low levels of decision selection and action implementation automation should be incorporated in high-risk functions, such as providing a clearance to prevent a conflict in dense airspace. Parasuraman et al. (2000) suggest this situation should only be automated at a low level so that there is more human involvement compared to the CRDA.

Dynamic Function Allocation/Adaptive Automation

Hopkin (1998) lastly suggests that automation cannot only be applied statically to different types of system functions at different levels, but it can also be dynamically applied to functions to switch control between the human and machine. Kaber and Endsley (1997) have labeled this concept as dynamic function allocation (DFA), or adaptive automation (AA). Adaptive automation uses one of five strategies for scheduling control allocations between the human and computers: (1) critical events – specific tactical events trigger control allocations (Scerbo, 1996); (2) operator performance measurement – operator mental states are inferred from primary or secondary-task performance and used as a basis for automation decisions (Kaber & Riley, 1999); (3) operator physiological assessment – proven and validated physiological measures (e.g., heart rate variability, electroencephalogram signals, eye movements, etc.) indicate workload and stress, and have been used to trigger DFAs (Freeman, Mikulka, Prinzel, & Scerbo, 2000; Scerbo, Freeman, & Mikulka, 2003); (4) system performance modeling – a pre-established pattern of system behavior is used to define a schedule of manual and automated control allocations (Scerbo, 1996); and (5) hybrid methods – one or more of the previously mentioned techniques are integrated (Parasuraman & Byrne, 2002).

The primary advantage of AA is that automation can be introduced when needed, reducing workload, yet maintaining operator involvement in the control loop thereby decreasing the likelihood of the automation consequences discussed in Section 1.2. In the context of ATC, automation can be introduced during periods of high workload (e.g., emergency procedures, high traffic density, aircraft non-conformance), when the controller most needs automation, and it can be shut-off during low workload periods (e.g., low traffic

density) to maintain controller involvement in the system (Hilburn et al., 1997; Parasuraman et al., 2000). A number of studies have provided evidence that this type of approach to automation can be beneficial (Kaber & Endsley, 1997; Hilburn et al., 1997; Clamann et al., 2002; Kaber et al., 2002; Kaber & Endsley, in press). Kaber and Endsley (1997) found that AA produced significantly superior performance than completely manual or fully automated control. Hilburn et al. (1997) found similar results. They conducted research to determine the effects AA has on decision making tasks in ATC using the previously described DA. They developed three different automation schemes including constant manual control, constant automation, and AA which introduced automation during high air traffic simulation periods (critical event scheduling strategy). They found that the AA condition resulted in the smallest increase in workload compared to fully manual and automated control.

Clamann et al. (2002) also conducted research to determine the effect AA has on HIP using forms of automation similar to those presented by Parasuraman et al. (2000). They found that “humans are better able to adapt to AA when applied to lower-order sensory and psychomotor functions, such as information acquisition and action implementation, as compared to AA applied to cognitive (planning and decision making) tasks” (Clamann et al., 2002, p. 346).

Another design parameter to address when incorporating AA into a system is the question of who will decide when automation will be invoked, or who has *decision authority*. There are two general forms of authority that can be considered, computer mandated and human mandated. In the former, a computer controller determines when automation is needed. The computer automatically switches “on” machine control of specific system functions. However, this form of authority can further remove the human from the system

control loop. The second form of authority, human mandated, may involve the computer suggesting DFAs to the operator, and the decision to switch to automation is left up to the human (Clamann & Kaber, in press; Kaber & Endsley, in press).

Adaptive Automation is currently being assessed as an option for reducing the workload associated with ATC while keeping controllers involved in system control loops and maintaining SA. Adaptive automation and other forms of advanced automation may be implemented in ATC in the future.

Free Flight

Another approach to future ATC that may incorporate a number of advanced automation systems is free flight. Currently, when aircraft fly under instrument flight rules (IFR) they establish a flight plan with ATC, which includes a particular flight path, altitude and flight times to fly to the aircraft's destination. If an aircraft needs to deviate from their established flight plan for any reason (e.g., weather, conflict, emergency procedures, etc.) they must communicate with ATC and request a change (Nolan, 1999).

The FAA has proposed a complete restructuring of ATC by 2010 that will incorporate *free flight*, which allows aircraft to autonomously fly any heading or altitude during any times that are convenient for the aircraft (Dillingham, 1998). If a change is needed, pilots simply redirect their flight without any communication with ATC.

New aircraft displays being developed for ATC of free flight present aircraft locations with protected and alert zones which controllers can use to safely monitor and, if needed, separate aircraft (Nolan, 1999). Only if a potential conflict arises do controllers intervene and actively resolve conflicts (Nolan, 1999; NRC, 1998). This form of advanced automation

has many benefits, including flight efficiency and cost reductions due to direct, streamlined routes, and reduction in ATC personnel and equipment requirements. However, free flight also presents many challenges associated with its implementation, primarily controllers being more OOTL during system operations.

1.4 Summary

Situation awareness is a prominent concept in human factors design and development of complex systems. It is the perception, comprehension, and projection of system states in an environment (Endsley, 1995a). Situation awareness is critical for air traffic controllers to maintain a mental picture of the airspace environment and the aircraft within that environment (Niessen et al., 1999). In order for controllers to maintain appropriate levels of SA, spatial, system, and task awareness are all important requirements (Wickens, 2002). Air traffic control is such a complex system, that controller awareness is critical to identifying and understanding concurrent goals and tasks (Endsley & Rodgers, 1994), and what the temporal sequence of cognitive activities is required for successfully accomplishing these tasks (Niessen et al., 1999).

Air traffic control requires high levels of cognitive processing, and one approach for alleviating the stress and workload among controllers is to allocate some controller activities to computers, or automation (NRC, 1997; Parasuraman & Riley, 1997). However, the introduction of automation, though providing many benefits when done properly, has potential disadvantages. One primary disadvantage of introducing automation in ATC is the possibility of removing the operator from the control loop (Endsley & Kaber, 1999). Forms of traditional automation may cause such problems and do not achieve the objective of

human-centered automation. Likewise, by removing the controller from the control loop, there may be adverse effects on SA (Wickens, 2002; Endsley, 1996; Endsley & Kiris, 1995; Kaber et al., 1999; Parasuraman & Byrne, 2002).

An option for maintaining controllers in system control loops while exploiting the benefits of automation is the use of more advanced approaches to automation including DFAs. Such forms of automation allow computers to accomplish parts of a task for the human at particular times during task performance (Hopkin, 1998; Kaber & Endsley, 1997; Wickens & Hollands, 2000). Adaptive automation can allow for the introduction of computer assistance to operators during different phases of a task when it is most needed (Hopkin, 1998). As technological development makes these forms of automation more readily available, and knowledge of implementation methods is developed, AA and free flight ATC systems may assume the future role of aiding controllers to improve air traffic efficiency.

2 Problem Statement

As discussed in the previous sections, SA is an important aspect of human-machine interactions in complex systems control. Numerous studies have defined methods for measuring SA (Endsley, 1995a; Endsley, 1995c; Endsley & Kaber, 1999; Hauss and Eyferth, 2003; Jones & Kaber, in press). A general result of applying these methods to the study of human-machine interaction is a clear understanding of how system designs, and automation in particular, can influence user SA. Endsley and Rodgers (1994) observed that SA is critical to ATC because of human interaction with highly complex automated systems. Numerous empirical studies have analyzed the impact of automation and SA in different contexts using various measures (Sarter, 1991; Carmody & Gluckman, 1993; Endsley, 1996; Kaber & Endsley, 1997; Kaber & Endsley, in press; Endsley & Kaber, 1999; Kaber, Onal, & Endsley, 1999).

Adaptive automation has been introduced in complex systems to prevent the shortcomings of conventional automation, including OOTLUF, but there is limited evidence on the extent to which AA may succeed in moderating operator workload and facilitating SA. Research is needed to describe the SA effect of AA in the context of advanced ATC systems. This study assessed the performance, SA and workload effects of AA of four different stages of HIP in an ATC simulation. The following objectives were established at the onset of the research:

(1) define a measure of SA in an ATC simulation that is a sensitive and reliable indicator of automation state changes as part of AA;

(2) empirically assess the SA measure for use in investigating the effectiveness of AA of various ATC information processing functions; and

(3) determine the influence of AA in an ATC simulation on operator SA.

The results of this study were expected to be used as a basis for developing a real-time measure of SA in ATC, which could be used as a trigger for DFAs in complex systems control in order to manage operator workload and potentially prevent OOTL performance problems.

3 Methods

The experiment conducted as part of this research involved human subject trials to measure performance, workload, and SA in a simulated ATC task under various modes of AA. The latest version of an ATC simulator, Multitask© (version 3.0), developed and used by Endsley and Kaber (1999), Kaber et al. (2002) and Clamann et al. (2002), was used in conjunction with a gauge-monitoring task as the research test-bed.

3.1 Tasks

3.1.1 Multitask

Multitask© is a low fidelity ATC approach control simulator. The objectives of an operator are to contact aircraft appearing on a radar display, make any necessary changes to pre-existing aircraft clearances based on their potential to cause a conflict, and safely land aircraft at one of two airports. One of four modes of automation (of various HIP functions as part of the task), and manual control, can be used in the simulation. Task performance is based on the number of aircraft safely landed at an airport, the number of aircraft that encounter conflicts, and the number of clearance amendments administered.

The simulator display includes a menu bar, radarscope, and control and status boxes (see Figure 3.1). The menu bar is used to select experimental trial settings, skill levels, and automation modes, all of which will be discussed in later sections. The radarscope represents approximately 15,000 square nautical miles (nm) of airspace within the users control, and is separated into four quadrants by horizontal and vertical lines, each delineating the north, south, east, and west cardinal directions on the display. Concentric circles are spaced on the

display, each representing 10 nm increments from the display center. Near the center of the radarscope are two airports, one 10 nm west of the center and another 10 nm east of the center (with 20 nm between the airports). Each airport has two runways. Eight equally spaced holding fixes, represented on the display by small gray circles, are located 30 nm from the center of the radarscope.

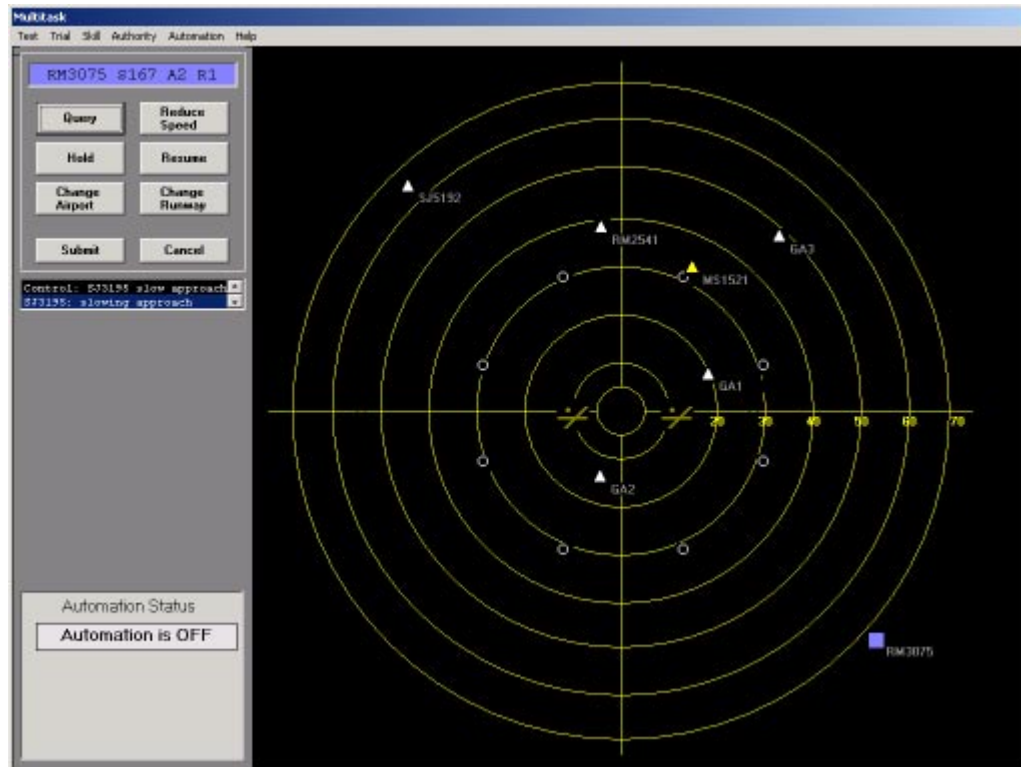


Figure 3.1 Multitask display in manual mode

Each simulated aircraft is represented on the display by a triangle icon and a data tag depicting the aircraft's call sign (see Figure 3.2). The aircraft data tag is similar to those found on ATC radar displays (NRC, 1997). The icons first appear at the perimeter of the display on one of eight approach trajectories and move toward one of the two airports,

destined for one of the runways. An aircraft's starting location, airport, and runway are all randomly assigned, and the aircraft appear one at a time with a 1-20 s buffer between aircraft.

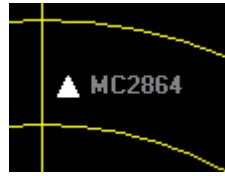


Figure 3.2 Aircraft icon

When an aircraft appears on the radarscope, it is presented as a flashing white triangle, indicating that it has not yet been contacted. Once an aircraft is contacted (selected and queried using a mouse controller), the icon becomes a solid white triangle, and the aircraft's predetermined clearance (including call sign, aircraft speed, destination airport, and destination runway) is displayed in a data box on the left side of the Multitask© display (see top of Figure 3.3). If an aircraft is placed in a holding pattern, the icon becomes yellow until the aircraft is advised to resume its approach to the destination airport, at which time it becomes white again.

The aircraft icons represent one of three possible types of aircraft: commercial, private, or military. The aircraft call sign is represented by an alphanumeric designator, including an aircraft type letter designator and a numerical designator as shown in Table 3.1.

Table 3.1 Aircraft designators

Aircraft Type	Letter designator	Four digit designator
Military	M	Sequential number
Commercial	Random 2-character airline designator	Random number
Private	GA	Sequential number

The three aircraft types occur in the simulation with different frequencies (see Table 3.2). The type of aircraft also dictates the possible range of speed for the vehicle. The exact speed is determined based on a standard amount of time required for each aircraft type to reach its destination (without a controller clearance amendment). The average time and speed values (real-time) for each type of aircraft are shown in Table 3.2. The destination airports include A1 for the west airport or A2 for the east airport, and the runways include R1 or R2.

Table 3.2 Aircraft type parameters

Aircraft Type	Frequency	Travel time	Average speed
Military	10%	21 minutes	200 kts
Commercial	70%	25 minutes	170 kts
Private	20%	42 minutes	100 kts

The control box allows the user to communicate with all of the aircraft currently on the radarscope and to request changes to aircraft parameters. It includes the previously mentioned data box, eight command buttons, and a history box (see Figure 3.3).



Figure 3.3 Control box

The data box is located on the top of the control box. The information in this box is displayed until another aircraft is contacted. The eight control buttons facilitate six clearance change commands, including query, reduce speed, hold, resume, change airport, and change runway. The two action commands include submit and cancel. The ‘Query’ command is used to initiate communication with an aircraft and obtain the aircraft’s flight identifier and parameters. The ‘Reduce Speed’ command simply reduces the aircraft’s speed by a set amount, and the original speed cannot be subsequently reassigned. The ‘Hold’ command is used to request that an aircraft fly directly to the nearest of eight holding fixes and remain there for either 30 min. or until advised to continue to their assigned airport and runway (the ‘Resume’ command). The ‘Change Airport’ and ‘Change Runway’ commands advise aircraft to change from their randomly assigned clearance to the other of the two possible destinations. The ‘Submit’ button must be used after selecting a desired clearance command, and ‘Cancel’ may be used to prevent an aircraft from further processing a command. All of the command keys are used to prevent possible conflicts between aircraft while maintaining efficiency (e.g., issuing the fewest number of clearance revisions). The history box, located below the command buttons (see Figure 3.3), displays the communications with the aircraft in text form, simulating actual ATC communications (e.g., GA4: Change airport).

Beneath the command box is an automation aid display box (see left-center of Figure 3.4). This box contains information pertinent to the current level of automation, and is inactive under the manual control (no automation) condition and information acquisition modes. The information in this box is described below for each mode of Multitask© automation.

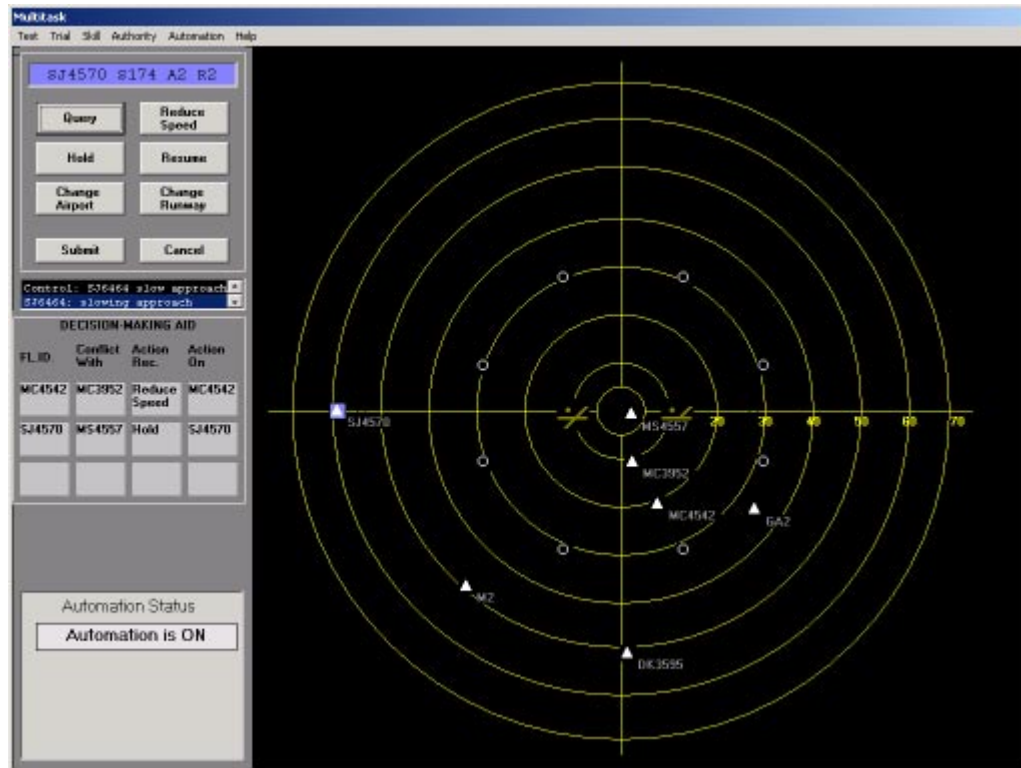


Figure 3.4 Decision making automation display screen

An automation status control box is located below the automation aid box and indicates whether automation or fully manual control is currently being utilized (see left-bottom of Figure 3.4). During AA trials when the computer intervenes in human operator control (mandated automation), the automation status control box displays, “Automation is ON,” and during manual control portions of AA trials (computer return of control to the human) the box displays, “Automation is OFF.”

Multitask© is capable of operating under one of the following five modes of automation during a simulation trial:

1. Manual control – No additional assistance is provided. Operations are performed as described in the previous sections (see Figure 3.1).

2. Information acquisition – A scan line rotates clockwise around the radar display, and as it passes over an aircraft icon, a Trajectory Projection Aid (TPA) for that aircraft is presented for 2 s. The TPA shows the aircraft destination and route in the form of a line connecting the aircraft and the airport or holding fix. The aircraft speed (in knots), destination airport, and destination runway are affixed to the center of the TPA (see upper-left radarscope quadrant of Figure 3.5). This mode of automation allocates the information gathering/data collection stage of HIP to machine control (Wickens, 1992). The ARTS and the TMA incorporate automation similar to this by including data blocks and graphic displays of aircraft tracks on radar displays (Debelack, Dehn, Muchinsky, & Smith, 1995; Nolan, 1999).

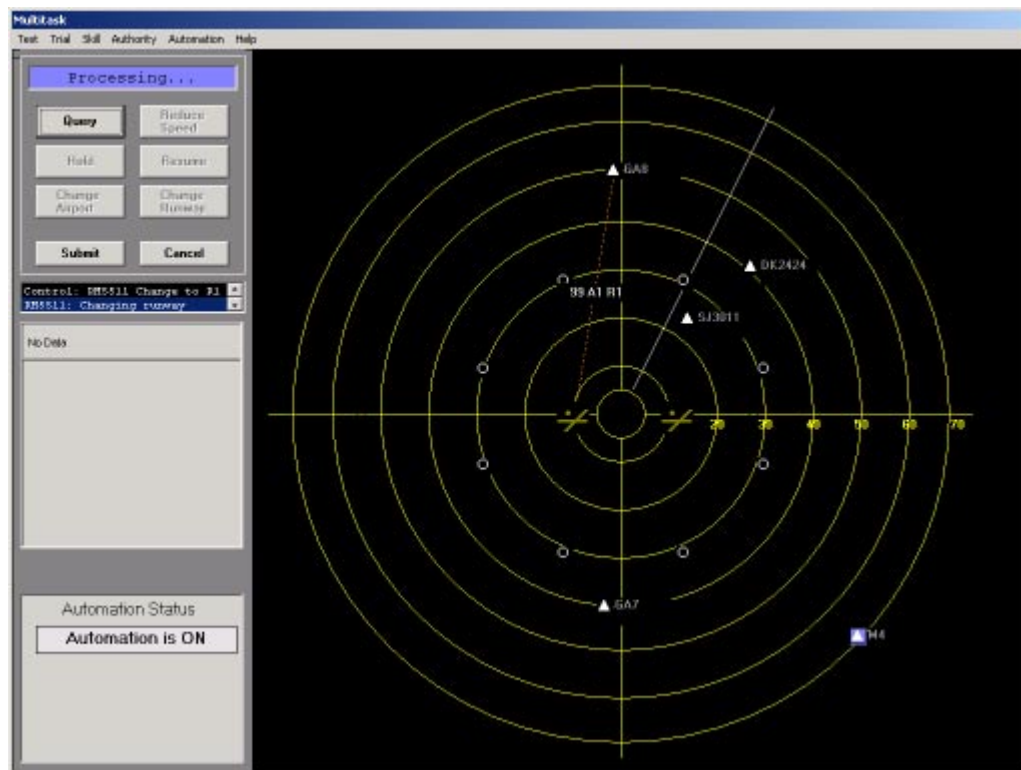


Figure 3.5 Information acquisition automation display screen

3. Information analysis – Information pertinent to each of the contacted aircraft on the radarscope is displayed in the automaton aid box including the aircraft's call sign, destination airport, destination runway, speed, and distance (nm) from the destination airport (see Figure 3.6). A final column in the table, 'Conf,' denotes the call sign of any aircraft that are currently in conflict with each other. This mode of automation may reduce operator workload associated with the integration of perceived information with long-term memories in working memory as part of HIP (Wickens, 1992). This mode of automation is very similar to the current User Request Evaluation Tool (URET) and the Prediction/Resolution Advisory Tool (PRAT) used by air traffic controllers, which alert controllers to potential conflict situations (Nolan, 1999).

ID	A	R	Spd	Dist	Conf
SJ3455	1	1	SPD1	54.7	
DK3955	2	1	SPD1	54.5	GA1
MS5580	1	2	SPD1	42.7	MC3365
RM3368	1	2	SPD1	16.7	
MC3365	2	2	SPD1	29.1	MS5580
GA1	2	1	SPD1	62.6	DK3955

Figure 3.6 Information analysis automation aid box

4. Decision making – In addition to conflict alerting, recommendations for conflict resolution are provided in the automation aid box. Information on conflicting aircraft, the recommended clearance change (speed, hold, resumption, airport, or

no option), and which aircraft to advise of a necessary change are all displayed together (see Figures 3.4 and 3.7). Up to three automated clearance recommendations are displayed in the automation aid box at a time and they are listed in order of priority. Runway changes are not recommended by the automation. This is an intended limitation in the automation in comparison to human manual control to ensure active operator involvement in the simulation. This mode of automation assumes responsibility for the HIP requirements associated with the decision and response selection aspects of the task (Wickens, 1992). It is similar to the conflict-resolution capability of the PRAT (Nolan, 1999).

DECISION-MAKING AID			
FL.ID.	Conflict With	Action Rec.	Action On
SJ6933	DK2668	Reduce Speed	SJ6933
MS1383	GA4	No Option	MS1383

Figure 3.7 Decision making automation aid box

5. Action implementation – This mode of automation simulates the hand-off of air traffic control from approach control to local-tower control, and the tower automatically maintains full control and responsibility of aircraft within 20 nm of the center of the radarscope. Automation of clearances for aircraft within this area prevents any conflicts (as described in the next section) after hand-off to tower control. The action implementation display includes a decision aid which

simply summarizes the classification and number of aircraft on the display (see Figure 3.8). The aid is included as part of this mode, in part, to facilitate consistency in the interface information content across conditions. Action implementation automation assumes the HIP requirement of response execution as part of the ATC simulation (Wickens, 1992). Proposed data link technology is currently being explored as a replacement for voice communication between controllers and aircraft (Debelack et al., 1995; Dillingham, 1998). One feature of this mode of automation, similar to the Multitask© action implementation mode of automation, is the computer automatically hands-off aircraft from one control sector to another (Nolan, 1999; NRC, 1997).

Class	Total	
Military	1	
Private	2	
Commercial	2	

Figure 3.8 Action implementation automation aid box

Each mode of automation is a unique mode of computer assistance simulating only one HIP function. That is, the modes of automation are not built-up from one mode to the next. For example, the information analysis mode of automation only provides computer assistance of the information analysis aspect of the task, not information analysis and information acquisition.

Multitask© performance is measured in terms of the number of aircraft cleared, aircraft conflicts, aircraft collisions, and the number of clearance amendments administered. This data is recorded during simulation trials and displayed at the end of the task (see Figure 3.9). Aircraft arriving safely at an airport are considered *cleared aircraft*. Aircraft traveling within 3 nm of another aircraft, as they travel towards their assigned airport, or aircraft that are within 20 nm of the center of the radarscope (second concentric circle) and destined for the same runway at the same airport, are considered *conflicts*. Aircraft that simultaneously arrive at the same airport destined for the same runway, or aircraft that come in contact with each other constitute *collisions*, in which case auditory feedback is provided and both aircraft are removed from the screen. In addition, the number of clearance changes, and successful and unsuccessful (nonconformance) changes are recorded as measures of performance. Unsuccessful, or nonconformance, changes result from either an erroneous controller request or a random, infrequent aircraft noncompliance simulating real ATC communication. In general, operators attempt to minimize the number of necessary clearance changes. (More details on the simulation performance measures are presented in the description of the independent and dependent variables of the experiment in Section 3.5.)



Figure 3.9 Multitask© performance measures

The experimenter controls the mode of automation applied to the simulation, the duration of trials, and the skill level. The skill level is defined by the number of aircraft (from 3 to 9) that are present on the radarscope at any given time. During all training and test trials as part of this experiment, 7 aircraft appeared on the radarscope from moment-to-moment.

3.1.2 Gauge-monitoring Task

The gauge-monitoring task used in this research was similar to the secondary task developed by Kaber and Riley (1999) and used by Clamann et al. (2002) and Kaber et al. (2002). It was a simple loading task which also contributed to the realism of the experimental test scenario, as human operators of complex automated systems are often required to perform multiple tasks simultaneously creating high workload conditions. It included a fixed scale, moving pointer display with a central “acceptable” range bordered on either side by two “unacceptable” ranges (see Figure 3.10). The acceptable range was colored green, the unacceptable ranges were colored red, and two small transitional areas

were colored blue. The transitional ranges were also considered “acceptable” gauge values. The user’s goal was to prevent the randomly drifting pointer from moving into either “unacceptable” range by maintaining it in the “acceptable” range using particular keys on a keyboard (‘Shift’ to move the pointer up or ‘Ctrl’ to move the pointer down) depending on which direction the pointer drifted. If the pointer drifted into an “unacceptable” range, depressing the appropriate key returned the pointer to the center of the “acceptable” range. After returning the pointer to the “acceptable” range, it continued to drift randomly until the end of a trial. The pointer did not dwell in an unacceptable region for more than 3 s at a time. Three seconds was determined by Clamann et al. (2002) as a sufficient amount of time for subjects to register a deviation while also performing the primary, ATC simulation. The design of the gauge task allowed for approximately six pointer deviations, or signals, to occur per minute with a variance of plus-or-minus one signal.

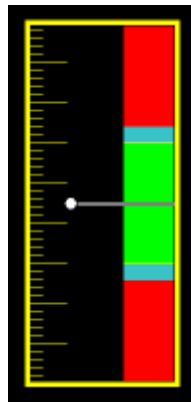


Figure 3.10 Gauge-monitoring display

Errors in the gauge-monitoring task were defined as the pointer deviating into either of the “unacceptable” ranges (a *signal*) without a control command from the operator to correct the deviation (a *miss*). Errors were also recorded when operators commanded an

unnecessary correction (a *false alarm*; e.g., a ‘Ctrl’ key press when the pointer was in the green or blue ranges).

The gauge task provided an index of operator workload in the Multitask© simulation. A low score in monitoring implied a high level of workload in the ATC simulation and vice versa. The task also served as a basis for invoking changes in the allocation of Multitask© functions from manual control to one of the modes of automated control. When secondary-task (gauge) performance was good, suggesting a reduction in operator workload, Multitask© returned to completely manual control.

In general, gauge task performance was recorded as a hit-to-signal ratio, or the number of times a subject detected the pointer in an “unacceptable” range, divided by the number of signals. Upper and lower performance bounds for gauge-monitoring were determined during subject training as part of the experiment for each mode of automation. Pairs of subjects performed gauge-monitoring practice trials under a randomly assigned mode of Multitask© automation, and their performance was used to establish primary task “overload” conditions for all subjects exposed to the same mode of automation during the experimental test trials. Pairs of subjects performed gauge practice trials for the information acquisition, information analysis, decision making, and action implementation modes of Multitask© automation. The upper and lower performance bounds were used as a basis for determining when DFAs should occur in the Multitask© simulation under the various modes of automation; that is, the AA was implemented based on operator secondary-task performance. These procedures are explained in more detail in Section 3.6.

3.2 Participants

Eight subjects were recruited to participate in this experiment from the North Carolina State University student population. Subjects ranged in age from 23 to 27 years. All subjects had 20/20, or corrected to normal, vision and personal computer experience. None of the subjects had flying or ATC experience. Subjects were compensated at a rate of \$10 per hour for their participation. Subject were informed of an additional incentive at the beginning of the experiment, a \$30 gift certificate, which was awarded to the top performer.

3.3 Equipment and Environment

The equipment used in the experiment included a high-performance graphics workstation with 512 MB of RAM and dual 2 GHz Pentium Xeon processors. Multitask© and the gauge-monitoring task were presented on two 17-inch, digital flat panel displays (see Figure 3.11). Two keyboards and two, 2-D computer mice were integrated with the computer system. Both the subject and the experimenter used a keyboard and mouse during test trials. The subject's keyboard and mouse were used to control the Multitask© and gauge-monitoring tasks, while the experimenter's interface controls were used to facilitate simulation trial freezes (second set of controls not shown in Figure 3.11).



Figure 3.11 Workstation

All trials took place in a small office with no windows and the overhead lights turned off to prevent glare on the computer screens. A small lamp was set up behind the computer monitors. A separate desk and computer were set up adjacent to the simulation workstation and were used by subjects to complete SA questionnaires (described in Section 3.5). The experimenter sat out of view of subjects and took particular care to not distract subjects while the simulation was running. Simulation freezes were periodically conducted to allow subjects to turn and respond to the SA questions at the second computer workstation while the experimenter obtained correct answers to the SA queries from the Multitask© console. The specific experimental procedures are discussed in detail in the following sections.

3.4 Experimental Design

The experiment followed a completely within-subjects design in which all eight subjects completed two, 30-min. trials under each of the five modes of Multitask© automation (i.e., the design was replicated to allow for estimation of experimental error). Each experiment trial consisted of both manual and automated minutes (with the exception of manual control condition trials which involved only manual minutes), depending on the DFAs that occurred during the ATC simulation on the basis of subject workload (as indicated by gauge-monitoring performance). Consequently, all performance, workload and SA response measures were calculated for both automated and manual control periods as part of AA trials. The experiment yielded 10 manual and 8 automated performance scores for each subject. In total, eighty composite performance observations (manual and automated minutes) were gathered across subjects (8 subjects x 2 trials x 5 control modes), and 64 manual and automated performance observations were collected (8 subjects x 2 trials x 4 control modes) on AA conditions (excluding the manual control condition trials).

3.5 Variables

The independent variable (IV) manipulated in this study was the mode of AA applied to the Multitask© simulation, including completely manual control, information acquisition automation, information analysis automation, decision making automation, and action implementation automation. Under the AA conditions, each mode of automation switched “on” and “off” depending upon operator workload states.

The dependent variables included Multitask© performance, which was recorded in terms of cleared aircraft, conflicts, and collisions. Another dependent variable was gauge-

monitoring task performance, recorded as a hit-to-signal ratio. Both of these measures were captured during each minute of a test trial.

Percent correct responses to SA queries were also recorded during the experiment using the Situation Awareness Global Assessment Technique (SAGAT), developed and validated by Endsley (1995a; 1995c). The SAGAT is a direct, objective measure of SA. One approach to developing SA queries as part of the SAGAT methodology is to conduct a GDTA on the simulation being used. A portion of a GDTA developed for the Multitask© subgoal “acquire aircraft information” is presented here (a GDTA for Multitask© is presented in its entirety in Appendix A):

1. acquire aircraft information

1.1 locate aircraft

in what display sector is the aircraft located?

aircraft position

how many other aircraft are located in that sector?

aircraft position

location of other aircraft

In the GDTA segment shown above, the goals and subgoals were broken-down to identify major decisions that must be made to accomplish the goals: “in what display sector is the aircraft located?” and “how many other aircraft are located in that sector?” These decisions led to identification of the perception, comprehension, and projection requirements for accomplishing goals in the Multitask© domain. These questions and SA requirements were used to develop SA queries (see Appendix B). Examples of a Level 1, 2, and 3 question used in this study are presented here:

Table 3.3 Level 1 example SAGAT question

Aircraft #	What is the aircraft's call sign ?
1	
2	
3	
4	
5	
6	
7	
Criterion:	none

Table 3.4 Level 2 example SAGAT question

Aircraft #	What is the aircraft's distance to destination? (nm)
1	
2	
3	
4	
5	
6	
7	
Criterion:	within 5 nm

Table 3.5 Level 3 example SAGAT question

Aircraft #	When will the aircraft arrive at the destination airport? (min from now)
1	
2	
3	
4	
5	
6	
7	
Criterion:	within 2 min

Endsley's (1995c) implementation of the SAGAT involves administering SA queries to operators during simulation trials. The SAGAT procedure requires the simulation to be frozen one or more times during a trial. Typically, the subject is presented with a map of the work environment and asked to locate various elements of the scenario (Jones & Kaber, in press). In this experiment, a radarscope display graphic was presented to subjects, and the subjects identified the current locations of the 7 aircraft on the display (see Appendix B). This graphic, or key, forms the basis for questions administered during the freeze. As the subject answers questions about specific aspects of the task, a computer or experimenter records the "ground truth" of the simulation scenario. Subsequent to responding to the questions, the simulation is resumed for the subject.

Endsley (1995c) identified several guidelines for implementing SAGAT including:

- The timing of the freezes should be random in order to prevent subjects from anticipating a query and to ensure queries do not occur during the same phases of a simulation or that they only occur during high activity.
- The queries should not occur within the first 3-5 minutes of a trial to allow a subject time to develop SA.
- Two queries should not occur within 1 min. of each other to allow subjects time to reacquire SA after a freeze.
- Multiple freezes during a trial are appropriate. Endsley (1995c) found that 3 stops during a 15-min trial did not adversely affect subject performance in a simulation.
- An entire experiment should collect 30-60 SA samplings per experimental condition.

Responses to SAGAT queries are scored as either correct or incorrect. Jones and Kaber (in press) said the SAGAT data provides diagnostic information on an individual query basis,

and the scores across queries are generally not aggregated. The responses to each query are typically analyzed separately; that is, all of the responses to one query are analyzed across conditions. Many researchers have effectively used this approach to SAGAT data analysis including the evaluation of pilot SA with aircraft cockpit systems (Endsley, 1995b), controller SA in ATC (Endsley & Kiris, 1995), and radar monitors in the theater of defense tasks (Bolstad & Endsley, 2000). Other recent research on SA in ATC (Hausse & Eyferth, 2003) has also demonstrated that analyzing SA questions individually can be an effective method on assessing controller SA. The results for each query are then generalized to the appropriate SA Level, and the scores for each experimental condition serve as a direct indicator of controller SA during those conditions. Jones and Kaber (in press) also describe a method of analysis in which SAGAT queries are categorized according to the levels of SA defined by Endsley (1995a) and composite scores for Level 1, 2, and 3 SA are computed based on the accuracy of subject responses to the sets of questions. This was the primary method of SA data analysis planned for this study. Statistical analyses of the SA scores in this study is discussed in more detail in Section 4.

The key advantage of the SAGAT is that it provides diagnostic information about specific elements of operator SA, which can be collected during a trial without increasing operator workload (Endsley, 1996; Jones & Kaber, in press). A disadvantage of SAGAT is its potential intrusiveness in operator performance; however, some studies have found that SAGAT stops are not disruptive to subsequent operator simulation behavior (Endsley, 1995c). The specific implementation of the SAGAT methodology in this experiment is described in the next section.

3.6 Procedures

Each subject participated in a simulation training and practice session, and 10 test trials. The overall schedule for the experiment is presented in Table 3.6. The procedures began with an introduction and equipment familiarization period. During this time, the subjects completed a demographic survey (see Appendix C) and their responses were included in a database for the experiment. An informed consent form, participation payment form, and contest rules and score sheet were also reviewed and signed by subjects during this period (see Appendices D, E, and F). It is important to note that the experiment duration presented in the informed consent form varies slightly from the final experiment schedule (10 and 13 hrs, respectively) due to the experiment lasting longer than expected. During the introduction and familiarization period, the subjects were also shown the computer system monitors, keyboard, and mouse to be used during the simulation.

Table 3.6 Experiment timetable

Day 1	Duration (min)
Introduction and equipment familiarization	15
Multitask© training under manual control	15
Gauge-monitoring training	5
Information acquisition automation training	15
Information analysis automation training	15
Decision making automation training	15
Action implementation automation training	15
Break	10
Adaptive automation training	15
Dual-task (Multitask© and gauge-monitoring) practice*	25
SAGAT familiarization	10
Dual-task and SAGAT practice*	50
Total:	205

Table 3.6 Experiment timetable (continued)

Day 2	
Simulation Review	15
Experimental trial 1**	50
Experimental trial 2**	50
Break	10
Experimental trial 3**	50
Experimental trial 4**	50
Break	10
Experimental trial 5**	50
Total:	285
Day 3	
Simulation Review	15
Experimental trial 6**	50
Break	10
Experimental trial 7**	50
Experimental trial 8**	50
Break	10
Experimental trial 9**	50
Experimental trial 10**	50
Debriefing	10
Total:	295
Total duration for both days: 785 (~13 hours)	
* Subjects were randomly assigned to modes of automation with equal numbers of subjects (n=2) experiencing each mode	
** The order in which subjects were tested under the various modes of automation was completely randomized	

Following the introduction and equipment familiarization period, a training and practice session was conducted. First, Multitask© and gauge-monitoring training was conducted. Then, participants underwent training sessions on each of the 4 modes of automation and the AA function of Multitask©. This training included descriptions of the modes, screen familiarization, and a short practice trial for each mode of automation. The simulation training was followed by a dual-task practice trial in which both the Multitask© and gauge-monitoring task were performed under a randomly assigned mode of Multitask©

automation. Subsequently, subjects were familiarized with the SAGAT, and sample questions were presented. Finally, a dual-task practice session, involving performance under the same randomly assigned mode of automation was conducted, with 3 SAGAT simulation freezes, each requiring subjects to respond to 6 SA questions. The SAGAT questions presented during the practice session were randomly selected from the questions to be posed during the actual experimental trials. Each subject performed the dual-task plus SAGAT practice trial under one mode of automation (see Table 3.7 for schedule of training and testing trials on a per subject basis), and the average gauge-monitoring task performance and standard deviation (SD) were recorded. These measures were used during the experimental trials involving the same mode of automation as a basis for triggering DFAs (manual and automated control periods). All of the familiarization, training, and practice portions of the experiment were conducted on the first day of subject participation.

During the second and third days of the experiment, subjects reviewed the simulation procedures and completed 10 experiment trials involving the use of the various modes of Multitask© automation. Each of the trials was preceded by a brief review of the mode of automation to be tested. Each subject completed two trials under each mode of automation. The order in which the modes were presented to subjects was randomized (see Tables 3.7). Each trial lasted approximately 50-min., including 30-min. of simulation time and approximately 20-min. to answer all three SA questionnaires.

The training, practice, and experiment sessions were conducted, as previously mentioned, using the Multitask© Skill Level of seven (i.e., 7 targets were presented on the display at any given time). The setting of seven targets was used based on the working memory capacity of 7, plus or minus 2, *chunks*, as defined by Miller (1956). All training and

practice trials presented the ATC simulation running 10-times faster than real time, with the exception of the dual-task and SAGAT practice session, and the experiment trials, which involved the Multitask© running 2-times faster than real time. These simulation speeds were determined appropriate based on previous research conducted by Clamann et al. (in press) which successfully incorporated similar accelerated speeds for training and testing. Furthermore, pilot testing suggested that 7 targets traveling at 2-times faster than real time was an appropriate level of workload for experiment trials.

The gauge-monitoring task was used as an index of workload and served as a basis for triggering the DFAs during AA trials. If gauge task performance dropped below the average practice performance minus 1 SD (as determined based on the two dual-task plus SAGAT practice sessions for the particular mode of automation being tested) for one minute of a trial (implying an increase in subject workload) then the computer initiated a switch from manual control of the Multitask© to the mode of automation for the trial. Therefore, the form of AA authority used in this study was computer mandates of DFAs. Once the automation was initiated, if subject performance in the gauge task increased above the mean plus 1 SD, or a hit-to-signal ratio of 1.0 was achieved (perfect performance) for one minute of a trial, then manual control was automatically restored. These criteria were developed by Kaber and Riley (1999) for a closed-loop AA system and validated by Clamann et al. (2002).

The dual-task plus SAGAT practice session and each experiment trial incorporated 3 SAGAT freezes. The freezes were designed to occur within one of three 8-min windows of time (7 to 14-min, 15 to 22-min, and 23 to 30-min) to ensure a sampling of SA throughout the testing. A random number generator was used to generate freeze times within each of the windows. Table 3.7 presents the minutes into a trial at which each of the freezes occurred.

The first six minutes were not considered for freezes in order to allow subjects time to acquire SA (Endsley, 1995c), and to allow the aircraft time to move from the radarscope periphery towards the airports. Furthermore, no two freezes were scheduled within 2-min. of each other in order to allow subjects time to reacquire SA after a stop (Endsley, 1995c).

Table 3.7 SAGAT freeze times

Subject	Mode Order	Automation Mode	Timing of simulation freezes (minutes into a trial)		
			Freeze 1 (7-14 min)	Freeze 2 (15-22 min)	Freeze 2 (23-30 min)
1	NA	Dual-task and SAGAT Practice: Info Acq	14	20	23
	10	Manual-1	11	16	26
	5	Manual-2	7	20	23
	4	Information Acquisition-1	12	20	23
	6	Information Acquisition-2	13	15	28
	3	Information Analysis-1	11	21	29
	8	Information Analysis-2	7	18	25
	1	Decision Making-1	11	19	26
	9	Decision Making-2	14	19	24
	7	Action Implementation-1	10	15	24
	2	Action Implementation-2	11	17	23
2	NA	Dual-task and SAGAT Practice: Info Anal	13	19	26
	2	Manual-1	8	22	27
	7	Manual-2	8	17	30
	8	Information Acquisition-1	13	22	26
	6	Information Acquisition-2	9	17	26
	5	Information Analysis-1	7	21	25
	10	Information Analysis-2	11	21	30
	9	Decision Making-1	14	18	30
	1	Decision Making-2	9	18	28
	3	Action Implementation-1	9	17	28
	4	Action Implementation-2	7	21	24
3	NA	Dual-task and SAGAT Practice: Act Imp	14	19	28
	7	Manual-1	8	22	24
	8	Manual-2	9	20	26
	3	Information Acquisition-1	9	16	30
	4	Information Acquisition-2	10	22	29
	6	Information Analysis-1	10	16	25
	9	Information Analysis-2	7	22	29
	10	Decision Making-1	13	21	24
	1	Decision Making-2	11	17	30
	2	Action Implementation-1	10	16	29
	5	Action Implementation-2	10	22	30

Table 3.7 SAGAT freeze times (continued)

4	NA	Dual-task and SAGAT Practice: Act Imp	10	17	30
	2	Manual-1	8	15	27
	1	Manual-2	10	18	30
	3	Information Acquisition-1	11	21	29
	6	Information Acquisition-2	9	18	26
	8	Information Analysis-1	13	21	28
	9	Information Analysis-2	14	16	28
	4	Decision Making-1	7	21	27
	5	Decision Making-2	14	22	24
	7	Action Implementation-1	9	15	24
	10	Action Implementation-2	13	17	26
5	NA	Dual-task and SAGAT Practice: Dec Mak	14	17	25
	3	Manual-1	9	20	23
	2	Manual-2	13	18	25
	8	Information Acquisition-1	14	16	30
	7	Information Acquisition-2	13	16	23
	9	Information Analysis-1	9	17	25
	6	Information Analysis-2	7	21	25
	10	Decision Making-1	14	19	27
	4	Decision Making-2	14	21	25
	1	Action Implementation-1	10	22	26
	5	Action Implementation-2	14	18	29
6	7	Dual-task and SAGAT Practice: Info Acq	8	22	29
	3	Manual-1	13	15	23
	6	Manual-2	7	19	24
	9	Information Acquisition-1	14	17	25
	4	Information Acquisition-2	14	18	25
	10	Information Analysis-1	9	21	30
	2	Information Analysis-2	14	20	28
	8	Decision Making-1	9	22	25
	5	Decision Making-2	13	16	23
	1	Action Implementation-1	8	17	28
	7	Action Implementation-2	10	19	29
7	9	Dual-task and SAGAT Practice: Dec Mak	12	21	24
	4	Manual-1	9	18	26
	7	Manual-2	10	16	23
	5	Information Acquisition-1	10	16	24
	10	Information Acquisition-2	11	19	30
	1	Information Analysis-1	7	16	28
	6	Information Analysis-2	12	18	26
	8	Decision Making-1	8	15	23
	3	Decision Making-2	10	15	25
	2	Action Implementation-1	12	18	26
	9	Action Implementation-2	13	22	24

Table 3.7 SAGAT freeze times (continued)

8	5	Dual-task and SAGAT Practice: Info Anal	9	20	25
	10	Manual-1	12	19	24
	6	Manual-2	9	18	26
	9	Information Acquisition-1	7	15	27
	8	Information Acquisition-2	14	16	29
	7	Information Analysis-1	11	16	24
	2	Information Analysis-2	14	16	29
	3	Decision Making-1	13	16	26
	1	Decision Making-2	8	16	24
	4	Action Implementation-1	13	15	27
	5	Action Implementation-2	10	20	26

During each freeze, subjects were posed with SA queries randomly selected from a pool of 18 total SA questions targeting the three levels of SA defined by Endsley (1995a; see Appendix B). Each freeze included 6 questions. At the beginning of a freeze, subjects were asked to identify the locations of the 7 aircraft on the radarscope by labeling a drawing of the radarscope with the numbers 1-7. Subsequently, they were asked to respond to each of the 6 SA queries for each aircraft by completing tables like those presented in Appendix B. The questions were administered electronically using a computer database application. While responding to SA questions, subjects were allowed to review question descriptions (see Appendix G), but the Multitask© display was not visible to subjects during queries.

Since Multitask© is truly an AA simulation in which a real-time workload measure is used to trigger DFAs between manual and automation control, it is not possible to predict at which moments during a simulation trial a subject will be using manual or automated control. Consequently, it was not possible to pre-determine a distribution of SAGAT stops during trials that could produce an even number of SA queries under manual and automated control conditions. However, since the SAGAT freeze times were randomly determined, there was an equal likelihood that the SA queries were posed during Multitask© manual control

periods or automated control periods. Since a large number of SAGAT freezes were conducted during the experiment, the average percent correct responses to SA queries under manual control or automated control was expected to be representative of actual operator SA.

The entire experiment lasted three weeks. Each subject was tested for approximately 13 hours over three separate days. The day-of-the-week and time of each subject's participation remained consistent during the experiment with the exception of two scheduling conflicts. At the start and conclusion of each day of testing, a payment form was completed and verified by the subject (see Appendix E). At the conclusion of the third day of testing, each subject signed the payment form, and they were debriefed. In addition, subjects completed a Closing Questionnaire (see Appendix H). A more detailed description of the experimental procedures is presented in Appendix I.

3.7 Hypotheses

Adaptive automation was expected to have a significant effect on ATC simulation (Multitask©) performance. It was expected that during the manual trials, Multitask© performance would be worse than during any mode of automation. This would be consistent with findings presented by Clamann et al. (2002) who observed that any AA of ATC information processing functions produced better performance than no automation whatsoever. In addition, as Leroux (1993), Laois and Giannacourou (1995), and Kaber et al. (2002) found, subjects have performed better using automation that provides assistance with low-level sensory/response functions, such as information acquisition and action implementation. Better task performance was also expected in this study during trials applying AA to these low-level HIP functions.

Adaptive automation was also expected to affect performance on the secondary, gauge-monitoring task, or operator workload. Modes of automation that require high levels of attentional resources may increase simulation workload, evidenced by decreases in gauge-monitoring task performance. For example, the information analysis mode of automation, though implemented to aid the user and improve simulation performance, presents a large amount of data and was expected to increase controller workload (Kaber et al., 2001). Likewise, modes of automation that do not present a great deal of information (e.g., action implementation) or present the information directly on the radar display (e.g., information acquisition) were expected to decrease workload. Furthermore, an overarching goal of implementing AA is to reduce operator workload compared to operating under full automation or manual control (Hilburn et al., 1997). Therefore, the experimental trials involving manual control were expected to result in higher levels of operator workload than the AA trials.

Finally, AA was expected to have an effect on operator SA. As Endsley (1995a) and Wickens (2000) observed, high levels of automation may result in OOTL performance, and can produce lower levels of operator SA. Therefore, subjects were expected to do better at responding to SAGAT queries posed during the manual trials of this experiment and manual control minutes of an AA trial than during periods of automation. Subjects were also expected to perform better on SAGAT queries during modes of automation that maintain user involvement in the system, like information acquisition (Kaber et al., 1999). With respect to action implementation automation, this mode automatically hands-off aircraft to tower control, eliminating the risk of a collision within 20 nm of the radarscope center. This mode was expected to improve Multitask© performance, but it also removes the controller

from the control loop and was expected to adversely affect SA. In addition, Kaber and Endsley (1997) found that low-level automation involving batch processing of operator task strategies lead to decreases in SA in comparison to other forms of automation maintaining operators in active control of the system.

Beyond this, the percent correct responses to Level 1 SA questions were expected to deteriorate during trials that involved the information acquisition LOA, because the subject was further removed from the system control loop in terms of gathering data on aircraft. Likewise, Level 2 SA query performance (pertaining to the comprehension stage of HIP) was expected to be worse under the information analysis LOA, because under that mode of automation the operator was removed from the process of integrating aircraft information to identify conflicts. In addition, decision making automation trials were expected to decrease the accuracy of responses to Level 3 SA questions, because active involvement in the decision process may affect a controller's ability to predict the future status of the simulation. Furthermore, decreases in the accuracy of responses to Level 1 and Level 2 SA questions were expected to decrease Level 3 SA accuracy, because the projection of future system status depends on accurate information perception and comprehension (Endsley & Rodgers, 1994; Endsley, 1995a).

4 Data Analysis

The experiment followed a repeated measures design (or randomized complete block design with blocking on the subject) in which each subject completed multiple trials under each level of the IV. As stated, the order of presentation of modes of automation to subjects was randomized. This design allowed each experimental unit to be used to compare the mode of automation effects on the various response measures and controlled for the variability among subjects (Montgomery, 2001, p. 127).

Analyses of Variance (ANOVAs) were conducted on all response measures (primary task performance, gauge-monitoring task performance, and SA) with the mode of AA and subject (to identify individual differences) included as predictor variables in the ANOVA model. Type III sums of squares were used to determine the significance of the IV on responses (SAS Institute Inc., 1990, p. 120-21). The mean square error (MSE) for the specific statistical models was used in all F-tests on the IV. For a repeated measures design with a single treatment, and the subject term included in the statistical model, Montgomery (2001, p. 624) states that this is the appropriate form of the F-test and that such a model partitions the variance attributable to the subject. (A conservative approach to assessing the significance of a treatment in human factors experiments is to use the mean square for the subject variable as a denominator in the F-test.)

Finally, post-hoc tests were conducted using Tukey's honestly significant differences test to determine which mode of AA produced superior results in terms of primary task performance, workload and SA. An alpha level of 0.05 was used to identify any significant effect of the mode of automation.

In order to make comparisons of the AA conditions with the manual control condition, the total number of aircraft presented in each trial was determined based on the number of aircraft contacted (or slewed) by a subject, and was used as a denominator in calculating ratios of aircraft cleared, conflicts, and collisions to total aircraft (i.e., cleared aircraft/aircraft slewed). This was done to account for any potential differences in the total number of aircraft presented across conditions.

The analyses of the response observations collected during the manual and automated control periods as part of the AA conditions were, however, not conducted in this manner, because the total number of aircraft generated during manual or automated control periods could not be determined on the basis of subject slewing of aircraft. It is important to recall here that there were always 7 aircraft on the simulation display at any given time, and the nature of the AA algorithm as part of the Multitask© simulator allowed for comparable amounts of manual and automated control time across modes of automation (although the *exact* proportions of manual and control periods is unpredictable). For this reason, the performance measures on the manual and automated control periods (as part of the AA trials) analyzed in this study consisted of the total number of cleared aircraft, conflicts, and collisions.

Two data points were removed from the aircraft conflict data as the result of a subject failing to follow instructions during two trials (Subject 7, Trials 3 and 4). This reduced the number of observations on conflicts for the experiment from 80 to 78 and decreased the number of conflict observations on the manual and automated control periods during the AA trials from 64 to 63 (one of the trials was a manual control condition trial). Two data points

were also removed from the collision data set as the result of an aircraft appearing on the radar display at exactly the same location as another aircraft (Subject 2, Trial 1; Subject 5, Trial 5). These two occurrences were considered to be problems with the simulation.

Workload Data Analysis

Subject workload was objectively measured in terms of the hit-to-signal ratio in the gauge-monitoring task. Average ratios were calculated for each test trial (including manual and automated control periods) and separate mean hit-to-signal ratios were calculated on performance during manual and automated control periods as part of the AA conditions. One observation was missing from the gauge-monitoring task data as the result of one (very short) automated control period not including any gauge pointer deviations (Subject 1, Trial 8). This decreased the number of observations for automation control periods to 63.

Diagnostics and Statistical Model

Subsequent to organizing the primary task and workload performance data into three data subsets (total performance, performance during automated control, and performance during manual control), data analyses were conducted using SAS. ANOVA model residual values were output and plotted against the model predicted values, mode of automation, and trial number to determine if the data met the assumptions of the ANOVA including random process, linearity, and constant variance. The normality assumption was also assessed using Shapiro-Wilk's test and normal probability plots. These diagnostics indicated if any transformations on the response or IV might be required to ensure the appropriateness of the parametric test, as prescribed by Neter, Wasserman, and Kutner (1990). Any transformations

employed in the various analyses are described in Section 5. Based on the residual and trial number plots no learning was found in either the Multitask© or gauge-monitoring performance data sets.

A statistical model in mode of automation and subject was used to assess the impact of the various AA conditions on response:

$$Y_{ij} = \mu + A_i + S_j + \epsilon \quad (\text{Equation 5.1})$$

for

$$i = 1, 2, 3, 4, 5$$

$$j = 1, 2, 3, 4, 5, 6, 7, 8$$

where

Y_{ij} = Response measure

A_i = Mode of automation

S_j = Subject

ϵ = Experimental error

Situation Awareness Data Analysis

On the basis of subject responses to the SA queries, the average percentage of correct responses to Level 1, 2, and 3 questions, and a total SA score, were determined for each stop. The type of simulation control, manual or automated as part of the AA conditions, was also recorded at each stop, and an analysis was conducted to identify any significant effects on SA. As previously mentioned, six of the 18 SAGAT questions were randomly assigned to each SAGAT stop resulting in 240 observations for the entire experiment (8 subjects x 10

trials x 3 stops). However, various occurrences resulted in the collection of less than the expected 240 observations:

- (a) based on responses to the SA questions, it was determined that Subject 1 did not understand Question 7 and Subject 8 did not understand Question 11 (see Appendix G for question descriptions);
- (b) some questions were not answered as a result of subjects inadvertently pressing a key on the computer keyboard or subjects deliberately closing the question window because they did not know any of the answers;
- (c) some SAGAT stops occurred in the last minutes of the simulation and posed questions for which the true answers were indeterminable (see Questions 14 and 17 in Appendix G); and
- (d) due to the random assignment of the 18 questions to trial stops, some stops did not incorporate any questions representing one of the three SA levels.

Subsequent to an analysis of the SAGAT data to determine any type of control (manual or automation) effects, the percent correct responses to Level 1, 2, and 3 SA queries, and total SA for each trial were analyzed for potential effects of the mode of automation. The percent correct responses to each individual SA question were also analyzed for sensitivity to the automation manipulation. As discussed previously, this approach to SAGAT data analysis has been used by many researchers (Endsley, 1995b; Endsley & Kiris, 1995; Bolstad & Endsley, 2000; Hauss & Eyferth, 2003; Jones and Kaber, in press) and is an appropriate measure of SA.

Each SA question at each stop solicited 7 responses from subjects (a response was required for each of the 7 aircraft on the display; see Appendix B); however, less than the 7 possible responses may have occurred during certain trials for the following reasons:

- (a) some subjects were not able to correctly identify all 7 aircraft on the SAGAT key (see the radar scope diagram in Appendix B) during simulation freezes;
- (b) some subjects did not respond to a particular question for all aircraft;
- (c) the true answers for certain questions were not obtainable for some aircraft on the display (e.g., minutes until destination is unknown when a trial ends with an aircraft in a holding pattern); and
- (d) some aircraft had not yet been contacted when freezes occurred, therefore some information was not yet available to the subject (e.g., destination airport).

These instances necessitated that the SA responses were scored as a ratio of correct answers to possible responses (i.e., the number of correctly identified aircraft was used as the denominator for SA question scores.)

Since the responses to SAGAT questions represent a binomial variable (correct or incorrect) the discrete nature of the responses violates the ANOVA assumptions. With this in mind, Endsley (1995c) found the arcsine function (e.g., $Y' = \arcsin(Y)$) to be an effective transformation to account for this problem in her use of SAGAT. The arcsine function was applied to the percentages for each question, and the effectiveness of the transformation was verified using the same diagnostic plots and tests considered in evaluating the performance data.

5 Results

5.1 Primary Task Performance (Multitask©)

Since significant individual differences were revealed through ANOVA results on a number of the response measures (primary task performance, workload and SA), power analyses were conducted for all statistical tests in order to provide some evidence of whether the sample size might have been influential in the findings. The β values for each statistical test are reported along with the test statistics and significance levels. Furthermore, power values are reported for specific insignificant results that were counter to expectation. In general, it is possible that the sample size for the experiment may have limited the sensitivity of some of the analyses for revealing true difference among the automation conditions.

Total Performance

The mode of Multitask© AA was expected to effect subject performance, however an ANOVA on total Multitask© performance (during manual and automated periods combined) revealed no significant effects of the mode of automation on the ratio of cleared aircraft, aircraft conflicts, and aircraft collisions to aircraft generated ($p>0.35$, $\beta>0.60$). This was surprising as 7 out of the 8 subjects (88%) commented on closing questionnaires that operating the simulation was easier when automation was provided.

Automated Control Periods

With respect to the automated control periods as part of the AA conditions, an ANOVA revealed a significant effect of mode of automation ($F(3,53)=4.03$, $p=0.0118$,

$\beta=0.54$) on the number of cleared aircraft. There also appeared to be significant individual differences ($F(7,53)=10.31, p<0.0001$). Analysis of Variance results also revealed the number of aircraft collisions during automated control periods to be significantly affected by the mode of automation ($F(3,51)=3.02, p=0.0382, \beta=0.33$). The initial analysis of conflicting aircraft during automation control periods revealed a significant Shapiro-Wilk's test ($p=0.0127$) and a departure of the data from a linear trend in the normal probability plot, suggesting a violation of the ANOVA normality assumption. Consequently, a Log_{10} transformation was applied to the response measures (Neter, Wasserman, & Kutner, 1990, p.146) attempting to account for the apparent normality violation. An ANOVA on the Log_{10} transform of the number of aircraft conflicts revealed no significant effect of the mode of automation ($p>0.60, \beta>0.85$). Figure 5.1 summarizes the mean number of aircraft cleared, conflicting, and colliding under each mode of AA during the automation control periods of the Multitask© simulation.

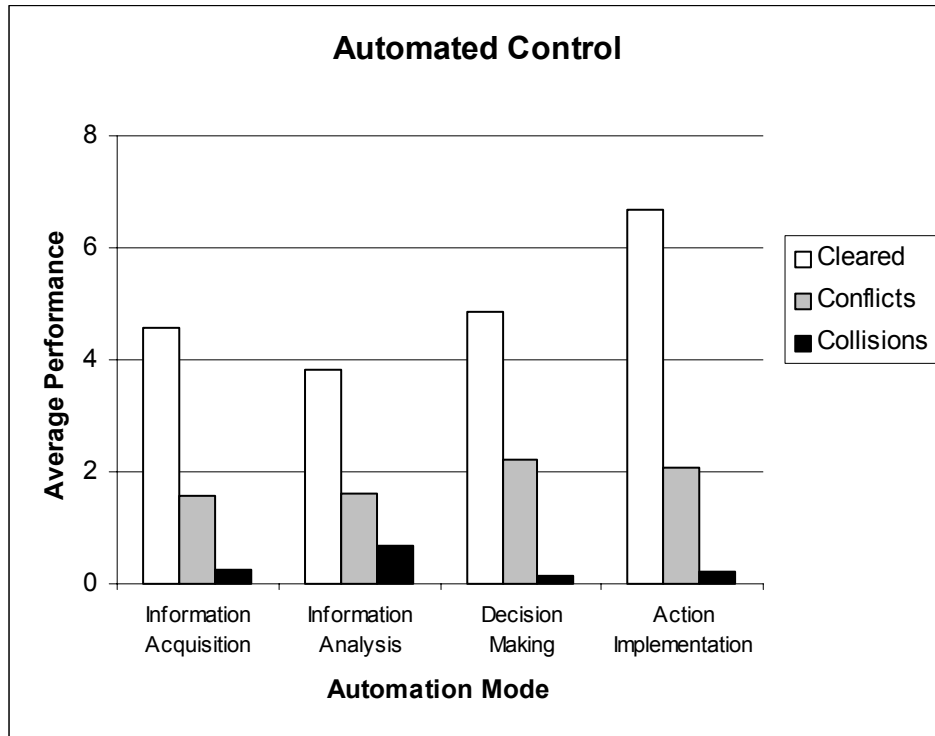


Figure 5.1 Primary task performance during automation control periods

It is apparent from the plot that, as hypothesized, the action implementation mode of automation, a low-level sensory/response function, yielded higher average performance during automated control periods in terms of cleared aircraft due to the automated hand-off of aircraft control from TRACON control to local tower control. A Tukey's test confirmed that action implementation was significantly better ($p < 0.05$) in terms of cleared aircraft, as compared to the information analysis mode of automation, a high-level air traffic controller cognitive function. Tukey's test also revealed information analysis to be significantly inferior ($p < 0.05$) for preventing collisions compared to decision making automation, further supporting the hypothesis that AA is most effective when applied to low-level cognitive functions.

Manual Control Periods

Residual diagnostics for the cleared aircraft data collected during manual control periods of the AA trials revealed non-constant variance across the modes of automation. A square root transformation was performed on the response data (Neter, Wasserman, & Kutner, 1990, p.146) in order to account for the potential ANOVA assumption violation. Analysis of Variance results revealed a significant effect of mode of automation ($F(3,53)=3.73$, $p=0.0166$, $\beta=0.64$) on the square root of cleared aircraft. There were also highly significant individual differences ($F(7,53)=8.39$, $p<.0001$) relating to cleared aircraft during manual control periods. Mode of automation did not prove to have a significant effect on the number of aircraft conflicts ($p>0.75$, $\beta>0.85$). An analysis of model residuals for the number of collisions during manual control periods revealed a significant Shapiro-Wilk's test ($p<0.0001$) and a departure of the data from the ANOVA normality assumption based on a non-linear normal probability plot. A square root transformation was applied to the response measure (Neter, Wasserman, & Kutner, 1990, p.146) which improved the conformance of the data with the normality assumption. However, the transformed data revealed no significant effect of the mode of automation on the square root of aircraft collisions during manual control periods ($p>0.65$, $\beta>0.85$). Figure 5.2 shows the mean values for the number of aircraft cleared, conflicting, and colliding during manual control periods of the AA simulation trials.

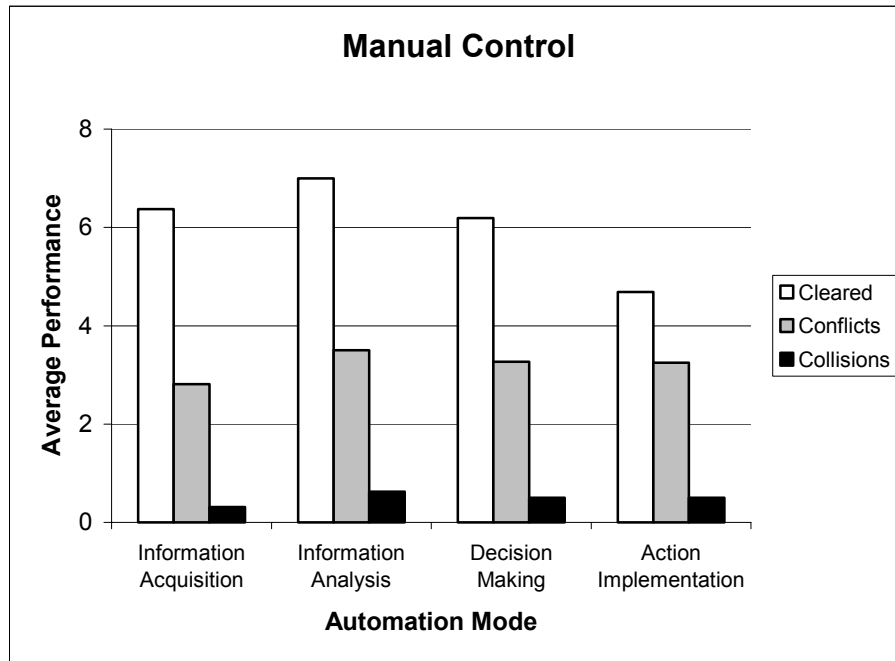


Figure 5.2 Primary task performance during manual control periods

Contrary to hypotheses, the plot shows higher average performance during trials involving the higher-level information analysis mode of AA in terms of cleared aircraft. A Tukey's test confirmed that the information analysis mode of automation was significantly better for clearing aircraft ($p < 0.05$) than the action implementation mode of automation. This carry-over effect is discussed in Section 6.

5.2 Secondary Gauge-monitoring Task Performance

Performance observations collected on the secondary task (workload) were organized into the same data subsets as the primary task performance data: performance recorded during both manual and automated control periods, performance during automation control periods as part of AA trials, and manual control performance as part of the AA conditions.

An ANOVA on the workload data did not reveal any significant effects due to the mode of automation when comparing the manual control condition with the AA conditions ($p>0.95$, $\beta>0.90$) or when analyzing the automated and manual control periods as part of AA ($p>0.75$, $\beta>0.85$ and $p>0.10$, $\beta>0.70$ respectively). These results are surprising as the modes of automation were expected to decrease workload (increased average secondary-task performance) compared to the manual control condition. Likewise, the information acquisition and action implementation modes of automation were expected to decrease workload compared to the other modes of automation. Closing questionnaire responses identified information acquisition as the preferred mode of automation for 6 out of the 8 subjects (75%). There were significant individual differences in secondary-task performance revealed through the comparison of the completely manual condition with AA conditions ($F(7,68)=16.97$, $p<0.0001$), and in analyzing the automated control periods ($F(7,52)=8.19$, $p<0.0001$) and manual control minutes ($F(7,68)=11.89$, $p<0.0001$) separately.

5.3 SAGAT Performance

Automation Versus Manual Control Results

The percent correct SAGAT responses at each freeze were analyzed to determine the effect of simulation control type (automated or manual control periods) on SA. As expected, an ANOVA revealed a significant effect of the general control type on the arcsine of percent correct responses to Level 3 SA queries ($F(1,216)=9.33$, $p=0.0025$, $\beta=0.75$); however, there were no significant effects of the general control type on the percent correct responses to Level 1 and 2 SA queries or for the total SAGAT scores ($p>0.20$, $\beta>0.90$), although there were significant individual differences ($F(7,216)=5.11$, $p<0.0001$). Figure 5.3 summarizes the

mean Level 1, Level 2, Level 3 and total SA scores for both automated and manual control periods.

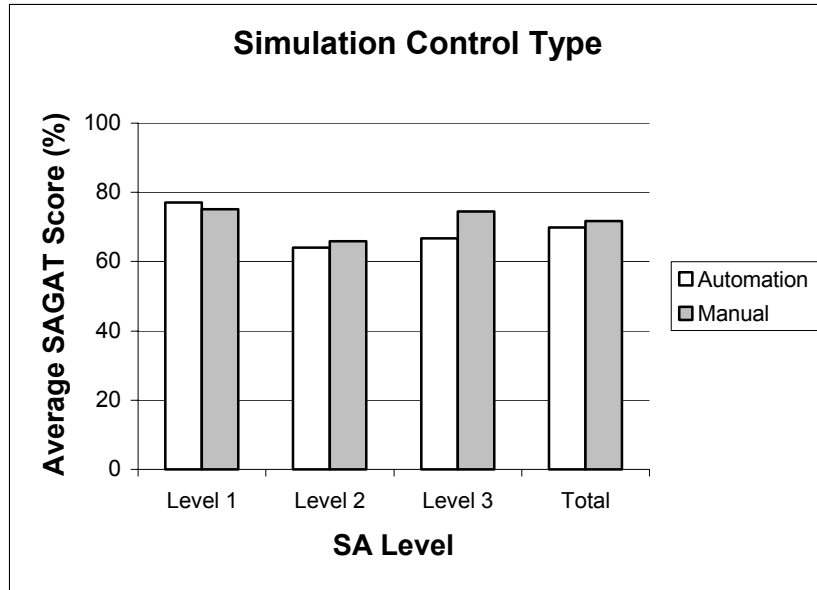


Figure 5.3 Mean SAGAT scores during manual and automation control periods

As hypothesized, the plot reveals that subjects were, on average, better at answering Level 3 SAGAT queries during manual control periods compared to automated control periods. In addition, closing questionnaire results revealed that 75% of subjects found answering the SA questions easier while the simulation was operating under manual control.

Results on Aggregate SA Measures

Surprisingly, none of the aggregate SA response measures revealed significance of the mode of automation ($p > 0.65$, $\beta > 0.80$). This was unexpected because the classification of various queries according to Endsley's (1995a) levels of SA was considered to be accurate

based on the type of dynamic knowledge the question called for. Further discussion of these results is presented in subsequent sections.

Individual Results on SA Queries

The SAGAT data was then analyzed on a question by question basis, resulting in 18 separate analyses. Most surprisingly, ANOVA results revealed no significant effect of mode of automation on the arcsine transform of percent correct responses for all questions, although significant individual differences were observed for SA responses to Questions 1, 3, 4, 5, 7, 10, 13, 14, 15, 16, 17, and 18 (see Appendix G for question descriptions). It was expected that SA would decrease during action implementation as the controller may have been OOTL compared to other modes of automation. In addition, the percent correct responses to Level 1 SA questions were expected to deteriorate during trials that involved the information acquisition LOA, Level 2 SA was also expected to be worse under the information analysis LOA, and decision making automation trials were expected to decrease the accuracy of responses to Level 3 SA questions. No significant findings were revealed for these analyses. This was unexpected because previous research on SA in ATC has demonstrated SAGAT to be a valid and reliable indicator of controller perception, comprehension, and projection for varying workload and display conditions (Endsley & Kiris, 1995; Endsley, Sollenberger, Nakata, & Stein, 2000). However, some more recent work by Hauss and Eyferth (2003) suggests that SAGAT may not be a sensitive measure for SA in the ATC environment due to different aircraft having different relevance to controllers at different times in a simulation. This and other potential shortcomings of the SAGAT

measurement approach are addressed in the Discussion section in explaining the lack of sensitivity of the measure in this study.

6 Discussion

6.1 Primary Task Performance (Multitask©)

Total Performance

It was expected that there would be significant performance differences among the modes of AA based on the unique functionality of the various automation aids applied to the ATC information processing functions. In addition, a significant difference was expected between the four modes of AA and the manual condition, as observed by Kaber et al. (2001) and Clamann et al. (2002). However, there was no significant effect of automation versus manual control, in general, on Multitask© performance. One explanation for this is the disproportionate number of manual and automated control periods during the AA trials. The AA trials involved shifts between automated and manual control based on operator workload states, and the information acquisition, information analysis, and decision making modes of AA all involved more manual control minutes than automated control minutes (59%, 63%, and 60% manual minutes, respectively). It is possible that the large numbers of manual control minutes as part of the AA conditions may have caused any differences between the modes of automation and the manual condition to be indiscernible by making them all perform more like a manual trial.

Automated Control Periods

During automated control periods, subjects produced superior primary task performance in terms of cleared aircraft during the action implementation trials. In addition, the information analysis mode of automation, a high-level function including a complex

information display, produced the highest number of aircraft collisions. These findings are consistent with the results of Leroux (1993), Laois and Giannacourou (1995), Kaber et al. (2002), and Clamann and Kaber (in press) who found automation applied to low-level sensory/response functions to be most beneficial when compared to complex cognitive functions.

Manual Control Periods

Although average subject performance was significantly worse during automated control periods as part of the information analysis condition, there appeared to be a positive carry-over effect of automation on subject ability to clear aircraft during manual control periods as part of the same condition. This finding suggests that information analysis automation may have better prepared subjects for manual control periods compared to the other forms of AA. However, this was not the case for subject ability to deal with negative events including conflicts and collisions. On average, there was a greater number of conflicts and collisions during the manual periods of the information analysis condition, but any differences among the AA conditions were not statistically significant. These findings relating to the information analysis mode of automation during manual control periods could be attributed to the fact that the average duration of manual control periods within this condition was larger than any other AA condition (remember, the performance measures for manual and automated control periods were recorded as the number of measure occurrences.) The lack of additional significant findings on the manual control periods may be attributed to the nature of manual control remaining consistent across the various modes of AA. Clamann

& Kaber (in press) also observed no significant findings relating to manual control periods of AA.

Defining Multitask© Performance Measures

The aircraft conflict performance measure did not reveal any significant effect of the mode of automation. Since the subjects in this study were naive students, their motivation for maintaining aircraft separation may have been far less than would be expected with actual controllers. Furthermore, the assessment of conflicts depended on an in-depth understanding of the simulation, and subject ability to mentally picture aircraft separation boundaries during the simulation. This was a complex task as part of the simulation. In regards to real ATC performance and safety, the aircraft conflict measure is a derivative of airspace regulations, and an aircraft conflict simply describes two aircraft that are flying in close proximity to each other. Therefore, two aircraft that are conflicting within a real ATC environment have not physically contacted each other nor have the people onboard the aircraft been harmed. By comparison, aircraft collisions almost certainly result in loss of life or injury to both passengers, crew members, and people on the ground in addition to immense financial loss. It was clear to all subjects in this study when a collision was imminent (conflict) and when one occurred. Similarly, the aircraft cleared performance measure is a direct indicator of controller efficiency. Aircraft cleared and aircraft collision performance measures are the most crucial to ATC, and the AA conditions significantly affected both of these measures in this study.

6.2 Secondary Gauge-monitoring Task Performance

Based on the results presented by Kaber et al. (2002), the AA conditions were expected to affect operator average workload. In their research, they observed higher levels of workload when AA was applied to the information analysis function of the primary task compared to the information acquisition and action implementation modes of automation. Furthermore, as Hilburn et al. (1997) suggest, experiment trials involving the manual control condition were expected to increase workload compared to the AA conditions, as implementing AA reduces operator workload compared to operating under full automation or manual control. However, the mode of Multitask© automation and the comparison of the manual condition to the AA conditions in this study did not reveal any significant differences in terms of gauge monitoring performance. Anecdotal observations during the experiment and subject responses to the closing questionnaire suggested high workload associated with the information analysis mode of automation due to the large amount of data displayed during these trials. Related to this, information acquisition was identified as the preferred mode of automation during closing questionnaires. However, there was no statistical evidence to support these suggestions. This lack in significant findings may be attributed to varying strategies employed by subjects to monitor the secondary task. Significant individual differences support this assertion. In general, these statistical findings presented here are consistent with Clamann and Kaber's (in press) findings that the type of automation does not significantly affect secondary-task performance (workload) during manual and automated control periods as part of AA applied to ATC-like tasks.

6.3 Situation Awareness

Automated Versus Manual Control Effects

As hypothesized, subjects were better at projecting the future status of the Multitask© air traffic (Level 3 SA) during manual control periods of the simulation as opposed to automated control periods. This finding supports the notion that introducing automation in ATC may remove the controller from the control loop (Endsley & Kaber, 1999) and lead to decrements in a controller's SA. Although the aggregate measure of Level 3 SA proved to be sensitive to the automation manipulation, surprisingly there was no significant effect of the mode of automation on the percent correct responses to individual questions. One possible explanation for the lack of individual SA question significance may be related to the level of workload assigned to the experiment trials. It is possible that 7 aircraft running 2-times faster than real time was not high enough of a workload to reveal significantly different SA across modes of automation. Further research is needed to determine appropriate levels of Multitask© workload in order for the SAGAT to be a sensitive and reliable indicator of the various modes of automation.

Effects on Aggregate Measures and Individual Queries

The limited number of significant SA findings in this research may also be attributed to the unique ATC environment simulated in this study (Multitask©). The ATC environment presents controllers with a vast amount of information. A load of seven aircraft was chosen as the minute-to-minute workload for this study, considering the working memory capacity defined by Miller (1956). However, the subjects were required to recall numerous flight parameters for each aircraft during SAGAT queries. Even when chunking is employed in

order to retain all of the aircraft parameters, the amount of information available within the environment may have exceeded the subjects' working memory capabilities.

Hauss and Eyferth (2003) suggested that controllers may use an event based mental representation of the air traffic situation in order to determine what information is currently relevant, what information will be relevant in the future, and what information can be neglected; thereby making the task manageable from a working memory perspective. In addition, Hauss and Eyferth (2003) state that aircraft which have recently been contacted by a controller and that have required recent control actions, or aircraft that are currently (or will soon be) in conflict, may demand more attentional resources than other display aircraft. Consequently, controllers may focus on certain aircraft to the exclusion of others at various times during control activities. Therefore, when using SAGAT to assess SA in ATC, controllers may be more or less prepared to respond to certain queries on certain aircraft. Hauss and Eyferth (2003) resolved that controllers will recall the flight parameters of aircraft most relevant to current task performance more accurately in responding to SAGAT queries than the parameters for aircraft that are not critical to ATC at the time of the SAGAT freeze. Gronlund, Ohrt, Dougherty, Perry, and Manning (1998) said that, "not all aircraft are equally important to the controller, and measures of SA should not assume that they are." It is possible that in the current study subjects responded accurately to SAGAT queries for the aircraft that they had recently dealt with and poorly for those aircraft not in the focus of their attention. Since each SAGAT query was posed for all 7 aircraft on the display at a freeze, from all data analyses perspective the average percent correct responses to a single query could have remained relatively constant across the experimental conditions as a result of this aircraft relevance issue.

Beyond this, Hauss and Eyferth (2003) state that expert controllers actually remember less about the ATC environment compared to novice controllers, because expert controllers, based on experience, know what aircraft are relevant and demand a heightened amount of attention. Niessen et al. (1999) agree that experience plays a large roll in controller SA, as experienced operators “use less information, but that this information is diagnostically more relevant” (p. 1513). The subjects in this study were not expert controllers, but they did receive 3.5 hours of training on the Multitask© simulation. Based on the residual and trial number plots, no learning was found, suggesting that the subjects did achieve some level of expertise in this ATC simulation. Therefore, the subjects may have remembered only what information was currently relevant to their clearance amendments. Using a SA measure that placed equal emphasis on aircraft they considered irrelevant at certain points in task performance may have been an insensitive measurement approach for the domain. Based on similar concerns, Hauss and Eyferth (2003) actually presented a method for SA assessment which weights aircraft based on their relevance to the current control scenario.

Finally, Hauss and Eyferth (2003) comment that, “a test is considered as content valid when it can be shown that the questions that are asked in the test are representative for the construct that the test is designed for.” The SAGAT queries posed in this research were based on Endsley and Jones’ (1995) GDTA of TRACON and a GDTA on the Multitask© simulation (see Appendix A). With this in mind, the measurement technique was considered to have good content validity. In fact, Endsley and Kiris (1995) and Endsley et al. (2000) have also developed SAGAT-based measures of SA in ATC and have demonstrated content validity through empirical research and association of SA results with performance outcomes. Hauss and Eyferth (2003) go on to say that, “any method that uses an unweighted

reproduction performance measure is not content valid... and cannot be considered as a valid method [in ATC]” (p. 422).

7 Conclusions

7.1 Caveats

Multitask© is a low-fidelity ATC simulation. Although its functions do simulate cognitive requirements of real ATC, it has several limitations when compared to true ATC displays and functions. First, Multitask© displays aircraft in a 2-dimensional environment and the simulation does not require normal 3-dimensional operations (i.e., altitude knowledge, vertical separation, vertical approach procedures, etc.). The 3-dimensional property of ATC adds immensely to the task's inherent complexity and increases the amount of information needed by a controller in order to maintain aircraft separation. The vertical dimension may affect controller task performance, workload, and SA.

The Multitask© simulation also lacks other ATC functions such as verbal communications, flight strip management, emergency procedures, and pilot inadvertent deviations from prescribed routes. These functions within true ATC add immensely to task workload. In an attempt to simulate true ATC workload associated with these demanding ATC functions, the simulation speed within this study was increased to 2-times the real ATC speed. As mentioned previously, this increase in simulation speed may not have raised task workload to the workload levels of real ATC operations.

The Multitask© simulation also does not evoke in users the stresses associated with clearing aircraft that are carrying human lives. It is possible that these limitations had a major impact of subject motivation and concentration in the simulation trials and, consequently, the workload, performance, and SA responses. Furthermore, the limitations of the simulation limit the generalizability of the results presented here to the real ATC domain.

Beyond the limitations of the study, based on the characteristics of the task, novice operators were used for this study. Although all subjects completed a very thorough training program and they may have been experts at performing the simulation, they still did not represent certified FAA air traffic controllers. Although this study revealed significant findings on AA in the ATC simulation and the implications for controller SA, the results may not be generalizable to expert ATC controllers due to the use of a novice subject population.

Finally, as mentioned previously, an unweighted SA measure which does not account for the varying emphasis that expert controllers may place on display aircraft may not be a valid measurement technique for the ATC domain. This study provides additional evidence to support this notion.

7.2 Design Implications for Future ATC Automation

The results of this study may be applied directly to the design of future ATC automation. Similar to results found by Leroux (1993), Laois and Giannacourou (1995), Kaber et al. (2002), and Clamann and Kaber (in press), this study determined ATC automation applied to low-level sensory/response functions to be most beneficial when compared to automation of complex cognitive functions. In regards to ATC automation design, low-level functions may include aircraft data collection, communications with aircraft, clearance amendments, and hand-off to other controllers. These types of ATC functions may benefit most from automation. Conversely, high-level ATC cognitive functions including aircraft information analysis, clearance decision making, emergency procedure decisions, and the comprehension of dynamic relationships between aircraft are not as well suited to automation.

However, when implementing AA in ATC, the automation effects may not be this straightforward. Significant results within this study demonstrate that the information analysis mode of AA may decrease task performance, but manual performance within this mode of automation showed significant improvements compared to the action implementation mode of AA. This suggests that controllers can benefit from AA of high-level cognitive functions similar to information analysis, if the control for this function is returned to the human periodically.

This study also revealed that a controller's ability to project the future status of controlled aircraft is directly impacted by automation. As mentioned above, a DFA scheduling scheme can be incorporated into ATC design in which automation is applied to ATC functions to decrease workload, but when the controller is required to project future aircraft states, manual control is returned. Future research in regards to a SA trigger for DFAs within ATC is addressed in Section 7.4.

7.3 Situation Awareness in Adaptive Automation of Air Traffic Control

This study attempted to define a measure of SA in an ATC simulation that is a sensitive and reliable indicator of automation state changes as part of AA. The SAGAT is one method for assessing SA within ATC. It involves first developing a GDTA, which identifies the goals, sub-goals, tasks and information requirements of controllers necessary to effectively separate and land aircraft. Secondly, SA requirements in the GDTA are used to form a comprehensive list of questions, which is used to objectively assess a controller's current perception, comprehension, and projection of elements in the ATC environment during simulation freezes. Previous research has demonstrated SAGAT to be a valid and

reliable measure of SA across many domains, including aircraft cockpit systems (Endsley, 1995b), ATC (Endsley & Kiris, 1995), and radar monitors (Bolstad & Endsley, 2000). However, the empirical assessment of the SAGAT measure developed in this study, in order to investigate the effects of AA of various ATC information processing functions, did not prove to be sensitive to the automation manipulations. Considering the recent results of Hauss and Eyferth (2003), mounting evidence suggests that there may be another necessary step to the assessment of SA in ATC. This step may be the weighting of aircraft parameters with their immediate importance to the subject air traffic controller based on current environmental factors.

A study similar to this using a weighted SA measurement technique is needed in order to empirically assess the utility of SA measures for investigating AA of various ATC information processing functions. The results of such a study could be used to determine the most sensitive and reliable weighting technique for discriminating AA conditions. Finally, a study incorporating such a weighting technique to measure SA may be used to determine the effect of AA in an ATC simulation on operator SA. Examples of potential weighting techniques are presented in the next section.

7.4 Future Research

Automation is currently implemented in ATC to alleviate workload placed on controllers while improving ATC performance and efficiency. Likewise, some manual control remains necessary to prevent controller OOTLUF and the negative human performance consequences (complacency, vigilance decrements, loss of SA). Adaptive automation has been proposed as an alternative to conventional automation that may provide

the benefits of moderating operator workload and consideration of OOTL performance problems. However, the precise relationship between the duration of DFA and the number of automation or manual control periods needed within a task are still unknown. Further research using various secondary-task criteria as bases for DFAs as part of AA is needed to describe the relationships between various proportions of manual and automated control to primary task performance and SA. In addition to defining these relationships, an optimum amount of automated and manual control time during AA should be found to maximize ATC and SA within a robust ATC simulation.

Additional research is also needed to validate the weighted SA measurement technique presented by Hauss and Eyferth (2003) within the Multitask© context. Two methods are applicable for applying this approach to Multitask©. First, an expert experimenter can, based on the current display setup, define which aircraft will be assessed during a SA freeze. These aircraft could be identified based on recent or expected clearance changes, aircraft currently in conflict, or objective measures of aircraft importance using eye-tracking equipment and a link analysis (i.e., index of importance). Secondly, the same procedure can be used as in this study, but subjects could be asked to weight the importance of queried aircraft in responding to SAGAT questionnaires. This weighting value (e.g., 1-5) would be multiplied by the SA score (percent correct responses to queries) to derive a weighted SA score.

Hauss and Eyferth (2003) attribute the need for a weighted SA measure to the unique complexity of the ATC environment requiring controllers to manage a large amount of information using an event based mental representation. As a result, varying levels of relevance are applied to each aircraft within the controller's airspace. It is possible that

relevance of stimuli or events to human performance in other domains, such as driving and piloting, may be important to consider in developing SA measures for studying, for example, in-vehicle highway systems or cockpit automation effects of pilot SA. Research is needed to identify other environments in which weighted SA measures may be applicable and useful. Subsequently, these SA measures may be used to assess the effects of AA of various HIP functions on SA within different contexts.

Once the effects of AA on SA are fully understood, future research is needed to develop a real-time probe measure of SA, which may serve as a basis for triggering DFAs. This method for allocating control between the operator and automation may produce superior results compared to, for example, a workload based trigger of DFAs. The criterion for this type of AA design would entail allocating control to automation only when the controller is fully “in-the-loop” and has achieved sufficient SA. However, once the controller has lost SA, manual control can be reinstated to increase perception, comprehension, and projection of system status.

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Appendices

Appendix A: Multitask© Goal-Directed Task Analysis

A GDTA is accomplished by first identifying major goals required for accomplishing the task. Secondly, major subgoals are determined that are essential for meeting the goals. Then, major decisions that are associated with each subgoal are developed and used to determine SA requirements for accomplishing the task (Endsley & Jones, 1995). These requirements focus not only on what data the controller needs, but also on how that information is integrated or combined to address each decision (Endsley & Rodgers, 1994, p. 4).

Endsley and Rodgers (1994) identify four caveats that relate to a GDTA:

- (1) At any given time, more than one goal or subgoal may be operating, although these will not always have the same priority. The analysis does not assume any prioritization among goals, or that each subgoal within a goal will always be relevant.
- (2) The analysis is based on goals or objectives, and is as technology-free as possible. How the information is acquired is not addressed.
- (3) The analysis seeks to determine what controllers would ideally like to know to meet each goal.
- (4) Static knowledge, such as procedures or rules for performing tasks, is outside the bounds of this analysis.

(Endsley & Rodgers, 1994, p. 4-5)

The following GDTA describes the goals and information requirements required to successfully clear and land aircraft at one of two airports in Multitask©; using the methods described by Endsley and Rodgers (1994) and Endsley and Jones (1995). Each major decision and SA requirement associated with a subgoal represents a level of information processing (perception, comprehension, or projection), and were used to develop SAGAT queries (see Appendix B). This analysis assumes expert performance (i.e., operator errors are not considered).

Directly following the GDTA is a description of a plan for accomplishing the goals within the Multitask© GDTA. Finally, a description of the Multitask© GDTA explains the task goals and subgoals in more detail.

(Note: Some decisions or questions make reference to other information/SA requirements. These requirements are emboldened.)

Goal	Subgoal	Decisions/SA requirements	Level of SA
0.	land aircraft safely		
1.	acquire aircraft info		
	1.1 locate aircraft		
		what display sector is the aircraft located? aircraft position	Level 1
		how many other aircraft are located in that sector? aircraft position location of other aircraft	Level 1
	1.2 contact aircraft		
	1.3 verify		
		is the aircraft queried (contacted)? aircraft icon (flashing or solid) aircraft parameters	Level 1
	1.4 acquire information		
		what is the aircraft type? aircraft call sign aircraft speed apparent velocity of aircraft	Level 1
		what is the aircraft call sign? aircraft call sign	Level 1
		what is the aircraft speed? aircraft speed apparent velocity of aircraft	Level 1
		what is the destination airport? destination airport apparent aircraft route	Level 1
		what is the destination runway? destination runway	Level 1
		what is the aircraft heading? destination airport apparent aircraft route	Level 2
		what is the distance to destination? destination airport	Level 2
		aircraft position (1.1)	
		what is the distance to nearest holding fix? aircraft position (1.1) location of nearest holding fix	Level 2
		what is the heading to nearest holding fix? aircraft position (1.1)	Level 2

location of nearest holding fix	
is aircraft speed representative of type?	Level 2
aircraft call sign	
aircraft speed	
apparent velocity of aircraft	
2. identify potential conflicts	
2.1 determine current relationships between aircraft	
what is the distance to other aircraft?	Level 2
aircraft position (1.1)	
location of other aircraft (1.1)	
what is the heading to other aircraft?	Level 2
aircraft position (1.1)	
location of other aircraft (1.1)	
do aircraft meet or exceed lateral separation?	Level 2
aircraft position (1.1)	
location of other aircraft (1.1)	
aircraft destination runway (1.4)	
other aircraft destination runways (1.4)	
2.2 predict future information	
what sector will aircraft be located in the future?	Level 3
aircraft position (1.1)	
aircraft destination (1.4)	
aircraft speed (1.4)	
apparent aircraft route	
will aircraft overtake each other?	Level 3
aircraft position (1.1)	
aircraft destination (1.4)	
aircraft speed (1.4)	
apparent aircraft route	
other aircraft positions (1.1)	
other aircraft destinations (1.4)	
other aircraft speeds (1.4)	
other apparent aircraft routes	
do aircraft paths cross each other?	Level 3
aircraft position (1.1)	
aircraft destination (1.4)	
aircraft speed (1.4)	
apparent aircraft route	
other aircraft positions (1.1)	
other aircraft destinations (1.4)	
other aircraft speeds (1.4)	
other apparent aircraft routes	
when will aircraft converge?	Level 3

	aircraft position (1.1) aircraft destination (1.4) aircraft speed (1.4) apparent aircraft route other aircraft positions (1.1) other aircraft destinations (1.4) other aircraft speeds (1.4) other apparent aircraft routes where will aircraft converge?	Level 3
	aircraft position (1.1) aircraft destination (1.4) aircraft speed (1.4) apparent aircraft route other aircraft positions (1.1) other aircraft destinations (1.4) other aircraft speeds (1.4) other apparent aircraft routes when will aircraft arrive at airport?	Level 3
3. decide which aircraft clearance needed		
3.1 choose aircraft to manipulate	which aircraft will need to be manipulated? potential conflict (2.2) aircraft capabilities projected effect on other aircraft	Level 3
3.2 choose operation	which operation should be used? potential conflict (2.2) operations which can be used aircraft capabilities projected effect on other aircraft	Level 3
4. provide clearance to chosen aircraft		
4.1 select aircraft		
4.2 select clearance		
4.3 submit		
4.4 verify	is aircraft conforming to assigned parameter(s)? changes to aircraft parameters (speed, route, etc) is aircraft conforming fast enough?	Level 1 Level 1

Descriptions: ATC goals in the context of Multitask

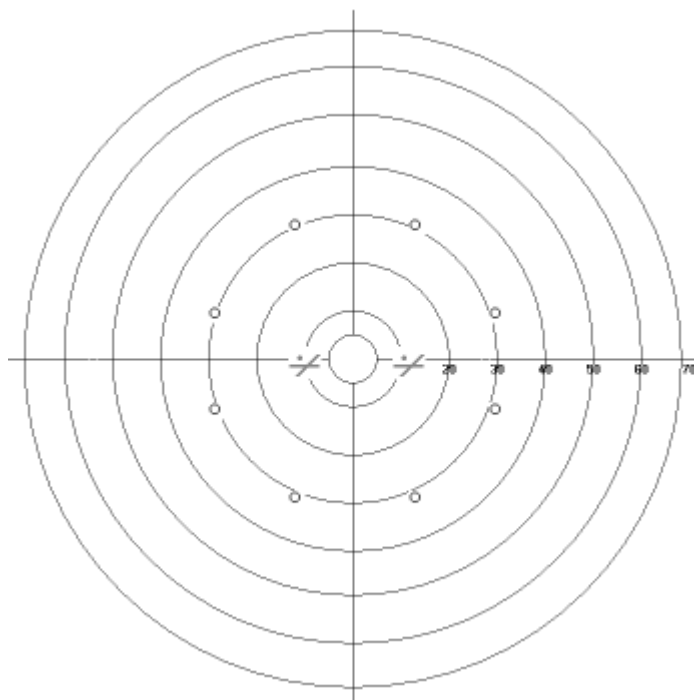
0. Land Aircraft Safely – The overarching goal of Multitask is to land the aircraft safely at either of the two airports. Actions that constitute unsafe flight are: (1) potential aircraft conflicts, and (2) actual aircraft collisions. The task goal is accomplished by successfully contacting the aircraft, analyzing each aircraft's information, and, if needed, issuing additional aircraft clearances.

1. Contact aircraft – Locate and maintain contact with aircraft on the display.
 - 1.1 Locate aircraft – Find aircraft on the display and place cursor on aircraft.
 - 1.2 Contact aircraft – Double-click left mouse button on top of aircraft. Click on 'Query' in the control box. Wait for 'Processing...' to finish.
 - 1.3 Verify – Confirm that the aircraft icon is no longer flashing. If the icon is still flashing, then repeat Steps 1.1 and 1.2.
 - 1.4 Acquire aircraft information:
 - Aircraft type – Military, commercial, or private.
 - Aircraft call sign – Alpha-numeric designation
 - Speed – Dependent on aircraft type
 - Airport – A1 or A2
 - Runway – R1 or R2 at the designated airport
 - Location – In relation to airports and other aircraft
 - Heading – Based on icon movement
2. Identify potential conflicts – Operators are required to determine if a potential conflict with aircraft is likely.
 - 2.1 Determine relationships between aircraft and two possible destinations
 - 2.2 Predict future flight parameters of aircraft and determine if a change in aircraft parameters is required
3. Decide which aircraft clearance(s) is/are needed – If a conflict is determined likely, the operator must decide the correct actions to take.
 - 3.1 Identify aircraft – Which aircraft need(s) to be changed?
 - 3.2 Identify operation – Which operation should be used to resolve conflict?
 - Reduce speed
 - Hold
 - Change airport
 - Change runway
4. Issue clearance – The proper operations are performed to resolve conflict
 - 4.1 Select aircraft – Double-click left mouse button on top of appropriate aircraft
 - 4.2 Select clearance – Chose the correct operation from the control box
 - 4.3 Submit – Press 'Submit' on the control box
 - 4.4 Verify clearance – Verify that the appropriate aircraft conformed to the assigned parameters (both from the control box script and the visual display); if the aircraft was issued a 'hold' clearance, a 'resume' clearance is required after the conflict is resolved

Appendix B: SAGAT Questions

Subjects marked on the below display where each aircraft, 1-7, was located at the time of a simulation freeze. The answers to the following questions were based on the numbers assigned to each aircraft. Subjects could refer back to this diagram and a list of question descriptions (see Appendix G) while answering questions. Subjects also received additional training on answering questions that referred to aircraft headings (see Level 2 SA questions).

Instructions: Using the following diagram, indicate where the 7 aircraft are currently located by randomly assigning a number 1-7 to each aircraft and writing the number on the graphic.



The tables below presents the queries to be asked during SAGAT freezes. Every column asks a question that must be answered for each aircraft (1-7). Every space has only one correct answer based on the current task situation. If needed, response criterion are identified below the question. Each freeze included a random selection of 6 questions from the pool of 18-questions.

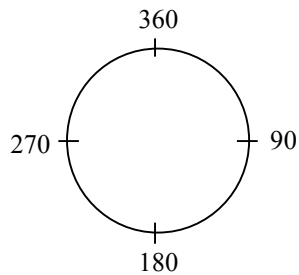
Level 1 SA Questions

	A	B	C	D	E	F
	What is the aircraft's call sign ?	Is the aircraft flying at its original or reduced speed ?	What is the aircraft's destination airport ? (A1 or A2)	What is the aircraft's destination runway ? (R1 or R2)	What is the aircraft's type ? (Military, Commercial, or Private)	Has the aircraft been queried ? (Y or N)
1						
2						
3						
4						
5						
6						
7						
Criterion:						

Level 2 SA Questions

	A	B	C	D	E	F
	What is the aircraft's heading ?* (degrees)	What is the aircraft's distance to destination ? (nm)	What is the aircraft's distance to the nearest aircraft ? (nm)	What is the aircraft's heading to the nearest aircraft ?* (degrees)	Does the aircraft meet or exceed lateral separation requirements ? (Y or N)	The aircraft shares its assigned route with how many other aircraft? (0-7)
1						
2						
3						
4						
5						
6						
7						
Criterion:	within 20 deg	within 5 nm	within 5 nm	within 20 deg	3nm or 20nm from center bound for same runway	

*The following diagram was presented when subjects answered items A and D.



Level 3 SA Questions

	A	B	C	D	E	F
	What clearance(s) will be required? (Hld, Red Sp, Ch Aprt, Ch Rwy, Resm, None)	If a clearance change is needed, when will the change be issued? (min from now)	Without a clearance change, will the aircraft overtake any other aircraft? (Y or N)	Without a clearance change, will the aircraft's path cross another aircraft's path? (Y or N)	When will the aircraft arrive at the destination airport? (min from now)	Rank the aircraft in the order that they will land/ sequence . (1-7)
1						
2						
3						
4						
5						
6						
7						
Criterion:		within 2 min			within 2 min	

Appendix C: Subject Survey

Survey

SubjectID Age Gender Handedness

Corrected Visual Acuity:
Left Eye: 20/ Right Eye: 20/

For the following questions, use this scale:

1	2	3	4	5
None		Occasional		Frequent

1. Rate your video gaming experience:

2. Rate your PC experience:

3. Rate your flying experience:

If you answered anything other than 1 for "flying experience", please explain:

4. Rate your Air Traffic Control experience:

If you answered anything other than 1 for "Air Traffic Control experience", please explain:

Appendix D: Informed Consent Form

Informed Consent Form Department of Industrial Engineering, North Carolina State University

SITUATION AWARENESS EFFECTS OF ADAPTIVE AUTOMATION OF VARIOUS AIR TRAFFIC CONTROL INFORMATION PROCESSING FUNCTIONS

I hereby give my consent for voluntary participation in the research project titled, "Situation Awareness Effects of Adaptive Automation of Various Air Traffic Control Information Processing Functions." I understand that the person responsible for this project is Dr. David B. Kaber, who can be telephoned at (919) 515-3086. He, or his assistant Chris McClernon, has explained to me the study objective of assessing situation awareness under various modes of automation of an air traffic simulation. He, or his assistant, has agreed to answer any inquiries I may have concerning the procedures of the research and has informed me of my right to refuse to answer any specific questions asked of me. He, or his assistant, has also informed me that I may contact the North Carolina State University (NCSU), Institutional Review Board for the Protection of Human Subjects by writing them in care of Dr. Matt Zingraff, Chair of IRB, Research Administration, NCSU, 1 Leazar Hall, Box 7514, Raleigh, NC 27695, or by calling (919) 515-2444.

Dr. Kaber, or Mr. McClernon, has explained to me the procedures to be followed in this study and the potential risks and discomforts. In summary the procedures include: (1) an equipment familiarization period; (2) training sessions including instructions on an air traffic control simulator, Multitask©, and its modes of operation; (3) a training session on a gauge-monitoring task; (4) a training session on dual-task performance involving both Multitask© and the gauge-monitoring task; (5) a training session on dual-task performance, including situation awareness questions; (6) ten experimental trials, and (7) appropriate breaks throughout the experiment. My experimental participation will take approximately ten hours spanning two consecutive days. The risks have also been explained to me as follows: (1) a potential exists for soreness of the hand and forearm muscles from extensive use of a mouse controller, and a standard keyboard in performing the Multitask© and gauge-monitoring simulations; and (2) a potential exists for visual strain and/or fatigue in viewing the simulation displays through a conventional PC monitor. These risks are not substantially different from those associated with my everyday PC use. In the event that I experience fatigue or discomfort, I will inform the experimenters immediately.

Information concerning compensation for my participation in this study has been explained to me as follows: (1) I will receive a payment of \$10.00 per hour for my participation in the experiment. The experiment is expected to last for approximately ten hours (approximately \$100 total). (2) I will be entered in a contest to receive a \$30 restaurant gift certificate based on my combined performance in the Multitask© and the gauge-monitoring task. (3) In the event that I choose to terminate my participation in the experiment, I will be paid for only the time I have

provided at a rate of \$10.00 per hour. (4) The researchers for the study have the right to terminate my participation if I am not cooperative or I experience discomfort or fatigue.

I understand that if this research project results in any physical or mental harm to me, treatment is not necessarily available at the NCSU, Student Health Services, nor is there necessarily any insurance carried by the University or its personnel applicable to cover any such injury. Further information about these matters may be obtained from the Institutional Review Board at (919) 515-2444, 1 Leazar Hall, NCSU Campus.

I understand that I will not derive any therapeutic treatment from participation in this study. I understand that I may discontinue participation in this study at any time without prejudice. I understand that all data will be kept confidential and that my name will not be used in any reports, written or unwritten.

Signature of Subject:

Date:

Signature of Authorized Representative:

(Chris McClernon)

Appendix E: Payment Form

PAYMENT FORM FOR SUBJECT

Situation Awareness in ATC Adaptive Automation

Name:

Address:

Email:

Phone:

Social Security Number:

	Day 1	Subject Initials	Day 2	Subject Initials	Day 3	Subject Initials
Date (XX/XX/03)						
Start Time (XX:XXam/pm)						
Finish Time (XX:XXam/pm)						
Total Time (XXXmin)						
Time x \$.1666 (\$10/hr)						

Total Due (Day 1 + Day 2 + Day 3) = \$ _____

I verify that the above information is correct,

Signature of Subject

Chris McClernon
Ergonomics Lab, NCSU IE

Please take this form to Mrs. Sankaran in the IE Department, Riddick room 331c.

Appendix F: Contest Rules and Score Sheet

Situation Awareness and Adaptive Automation Contest Rules and Score Sheet

This form describes the Situation Awareness (SA) and Adaptive Automation contest rules, indicates your intent to participate, and serves as the verification of your score. If you are participating in the contest, you must keep this form until the results of the contest are reported.

Prize: This contest will have one winner, who will receive a **\$30.00 gift certificate** to the 42nd Street Oyster Bar, located at 508 West Jones Street, Raleigh NC (919.831.2811).

Scoring: Score will be calculated according to the following formula:

$$\text{Total score} = [(x + y + z)/a] + g$$

Cleared aircraft (x) = +1

Conflicts (y) = -.5

Collisions (z) = -1

Amendments (a) = sum of clearance changes

Gauge-monitoring errors (g) = -1

This formula will be applied to the data collected during your performance in all 10 experiment trials (30 minutes each) to produce a combined total.

Redeeming your prize: The winner will be contacted within one week after the last experimental trial (Middle of September; make certain that you provided your correct contact information on the Subject Info database).

All questions should be directed to Chris McClernon at mcclernonck@hotmail.com

☐ I have read and understand the contest rules, and I wish to participate.

☐ I do not wish to participate.

Participant Signature

Date

Chris McClernon

Subject Number	
Score	

Appendix G: SAGAT Question Descriptions

1. What is the aircraft's call sign?

Provide both the letters and numbers that make up the aircraft's call sign (ex. NC3999, M8, GA9, etc.)

2. Is the aircraft flying at its original or reduced speed? (original or reduced)

Determine if the aircraft is flying at its originally assigned speed, or if a 'Reduce Speed' command has been issued.

3. What is the aircraft's destination airport? (A1 or A2)

Identify the airport the aircraft is currently assigned to land at.

4. What is the aircraft's destination runway? (R1 or R2)

Identify the runway the aircraft is currently assigned to land on.

5. What is the aircraft type? (Military, Commercial, or Private)

Based on the call sign and speed: military aircraft are the fastest and are denoted by the letter 'M' followed by a sequential number; commercial aircraft fly at intermediate speeds and are denoted by two random letters followed by 4 random numbers; private aircraft are the slowest and are denoted by 'GA' followed by a sequential number.

6. Has the aircraft been queried? (Yes or No)

Determine if the aircraft has been contacted, or is it still flashing. Aircraft currently being processed ('Processing...') are not yet queried.

7. What is the aircraft's heading? (degrees)

Using the compass diagram, determine in what direction the aircraft is traveling towards its destination, whether it be an airport or a holding fix. If currently at a holding fix, the heading should read zero.

8. What is the aircraft's distance to destination? (nm)

In nautical miles, determine how far the aircraft is from its destination, whether it be an airport or a holding fix. If currently at a holding fix, the distance should be zero.

9. What is the aircraft's distance to the nearest aircraft? (nm)

In nautical miles, determine how far the aircraft is from the nearest aircraft.

10. What is the aircraft's heading to the nearest aircraft? (nm)

Using the compass diagram, determine in what direction the nearest aircraft is.

11. Does the aircraft meet or exceed lateral separation requirements? (Yes or No)

An aircraft is **not** meeting minimum separation requirements if: (a) the aircraft is within 3nm of another aircraft, or (b) two aircraft are within 20nm of the radarscope center and are bound for the same runway at the same airport.

12. The aircraft shares its assigned route with how many other aircraft? (0-7)

A route is a straight line connecting the aircraft's current starting point and destination (i.e., a starting location and holding fix, a holding fix and airport, or a starting location and airport). If two aircraft are flying the same direction on the same route, no matter how far apart they are, they are sharing a route.

13. What clearance will be required?

If an aircraft is at a holding fix, it must receive either a 'Resume' or 'Change Airport' command to continue towards its destination. Aircraft that may collide in the future may also require clearance changes. Aircraft outside the holding fixes may only be issued a 'Reduce Speed' and 'Hold' command. Aircraft inside 30nm on the radarscope may only be issued a 'Reduce Speed' and 'Change Runway' command.

14. If a clearance change is needed, when will the change be issued? (min. from now)

Based on the current status, determine (in minutes from the current time) how soon a change will be issued. If no change is required, answer 'NA'.

15. Without a clearance change, will the aircraft overtake any other aircraft? (Yes or No)

Determine if the aircraft shares its route with any other aircraft, and if the two aircraft will collide as a result of one aircraft flying past the other aircraft.

16. Without a clearance change, will the aircraft's path cross another aircraft's path? (Yes or No)

Based on the current status, determine if any of the aircraft's current routes cross each other, regardless of lateral separation.

17. When will the aircraft arrive at the destination airport? (min. from now)

Determine when an aircraft will land.

18. Rank the aircraft in the order that they will land. (1-7)

Determine when an aircraft will land in relation to the other aircraft.

Appendix H: Closing Questionnaire

What was your strategy for clearing targets and controlling the gauge?

Did you think it was easier or more difficult to use the automation?

Was it easier to answer SA questions while the simulation was operating under automation or manual control?

Which form of automation was most useful?

Are there any improvements that can be made to the training?

Are there any improvements that can be made to the interface or to the controls of either task?

Appendix I: Subject Instructions

Day 1

I. Introduction

[Add “Date” and “Start Time” to the front cover of the subject’s folder. Show subjects where the bathroom, restroom, drinks, snacks, and personal storage space on shelf is. Explain that subjects may only have a snack or drink during one of the breaks. Ask subjects to turn their cell phone off. Place the “Experiment in Progress” sign on the door.]

Welcome and thank you again for volunteering to participate in this experiment. This experiment is funded by NASA and its results will help design better air traffic control, or *ATC*, systems in the future. This experiment is being conducted to study the effects of automation on operator situation awareness in an air traffic control simulator and a gauge-monitoring task. The ATC task will require you to use a standard PC mouse to safely guide aircraft in landing at airports. The gauge-monitoring task will require you to use a standard PC keyboard to maintain a moveable pointer within an ‘acceptable’ range on a fixed scale. Different levels and durations of computer assistance will be provided in performing the tasks. In addition, a series of questionnaires will be administered during freezes in the simulation to test your knowledge of current and future states of the ATC task, or assess your *situation awareness*.

The procedures to be followed include **[present the experiment schedule to subject]**:
an equipment familiarization period;

a 15-minute training session, during which you will be provided with instructions on manual radar monitoring;

a 5-minute training session on the gauge-monitoring task;

a 60-minute training session on four different modes of automation of the ATC simulation;

a 15-minute training session on adaptive automation of the task;

a 25-minute practice session involving both the radar monitoring and gauge-monitoring tasks;

a 10-minute situation awareness questionnaire familiarization; and

a 30-minute practice session requiring you to perform the radar monitoring and gauge-monitoring tasks, and to complete the SA questionnaires (this practice will be representative of the experiment trials).

These steps will all be conducted on the first day of the experiment. On Day 2 and Day 3 of the experiment, you will perform the following:

a 15-minute simulation review at the beginning of each day;

ten, 30-min test trials including manual control and automation of the ATC task; and

a debriefing at the conclusion of each day.

The total expected duration of the experiment over the three day period is approximately 13

hours. You will be provided with breaks at least every 90-minutes during your sessions.

You are asked to complete all experimental testing; however, you may discontinue your participation at any time and you will be paid for any amount of time you participated. If you withdraw from the experiment without completing all of the test trials, you will not be eligible for winning the contest gift certificate.

All experiment instructions will be presented to you verbally. If you do not understand certain instructions, you will be able to ask questions during each training phase. You must carefully follow all instructions given before and during the experiment. If you fail to follow instructions or the computer equipment malfunctions, I will stop testing. In these cases, you will be allowed to read the task instructions and ask any questions you may have, or I will correct the system malfunction. Once your full comprehension of the instructions is ensured, and the equipment is in working order, testing will re-commence. Do you have any questions about the experiment procedures?

Subject Info

[Have subjects sit in front of secondary computer. Open the SAGAT application, select “Subject Info”, and enter subject ID number.]

You will first be asked to enter your information into a database. Your Subject ID has already been entered. Please fill in the rest of this form. When you are done, select “Return to Main Menu.”

Subject Survey

Next you will complete a Subject Survey. Please click on “Subject Survey” on the computer interface. This form asks you questions about yourself and verifies your qualifications for the study. Please take a few moments to complete the survey. If you have any questions, I will be happy to address them.

[Verify subject is entering valid data for participation.]

Informed Consent Form

[Give the subject the informed consent form. Summarize the form and encourage the subject to read the form.]

Next you will review and sign an Informed Consent Form. This form summarizes the information that has been presented to you thus far and identifies the persons responsible for the study. The form also addresses North Carolina State University's liability in conducting this experiment. I encourage you to read the form. In order to participate in this study, you must have at least 20/20 corrected vision and some computer experience. Extensive flying or ATC experience may also prevent you from participating in this experiment. Potential risks include: (1) soreness of the hand and forearm muscles from extensive use of a mouse and keyboard; and (2) visual strain and/or fatigue in viewing the simulation displays through a conventional PC monitor. These risks are not substantially different from those associated with everyday PC use. In the event that you experience fatigue or discomfort, please inform me immediately.

Please sign and date both copies of the form.

[While the subject is reviewing and signing the forms; select "Print Payment Form" on the SAGAT application, verify the subject information, and print.]

[Give one copy to the subject to keep.]

Payment Form

[Record the date and time the subject started participation from the front cover of the subject's folder. Have subjects verify their information on the payment form.]

This is the payment form that will be used to calculate your compensation for participating in the experiment. Please verify that the information you provided is accurate. **[Wait.]** Verify that I have filled in the correct start date and time, and initial by those blocks. I will complete this form for you during the three days of the experiment, and I will ask you to initial by all of the blocks as I fill them in. We will both sign the form on the last day. It is imperative to confirm the correct start and stop times for each testing day on this form, as it will determine how much you are paid.

Contest Rules

[Present Contest Rules and Score Sheet to the subject.]

By participating in this experiment, you are eligible to win a prize. The participant who attains the highest combined score in both the simulation and the gauge-monitoring task during all 10 experiment trials is eligible for a \$30 gift certificate to the 42nd Street Oyster Bar and Restaurant in downtown Raleigh.

The information on this form includes the rules of the contest, the equation used to compute your score, the instructions for redeeming the prize, and also serves as a verification of your score. In order to redeem your prize, you must present this form to the experimenter. If you wish to participate, please sign and date the form at this time. I will enter your score in the blank at the bottom when you complete the experiment trials. If you have any questions about the contest, I can answer them now.

That concludes the administrative portion of the experiment. Do you have any questions about your participation in the study?

II. Familiarization

Now I will familiarize you with the testing equipment. **[Direct subjects to sit in front of the Multitask display.]** The experiment equipment is comprised of two displays, a full-size keyboard, and a mouse controller, which have been set up here to resemble a typical working scenario in a ‘radar’ monitoring operation. The displays are high-resolution graphics monitors commonly used with PC-based computing systems. During training and actual testing, the room will be darkened to eliminate any glare reflected off the surfaces of the displays. The keyboard is a standard 124 key unit. You will only be required to use the control, shift, and enter keys. **[Point to the keys that will be used.]** The mouse is a simple controller facilitating movement of the cursor on the ‘radar’ monitor in both the horizontal and vertical directions.

This completes a brief overview of the testing equipment you will use. Do you have any questions concerning the setup?

III. Multitask Training

[Start Multitask and the Gauge-monitoring task. Turn off gauge-monitoring computer monitor. Turn off overhead lights, and turn on desk lamp.]

You will now receive training in the MultiTask ATC simulator. The ‘radar’ monitoring task involves clearing randomly appearing graphic targets in the form of small white triangles.

The triangles represent either military, commercial, or private aircraft. Military aircraft may

represent a fighter aircraft, like an F-16; commercial aircraft may represent an airline aircraft, like a Delta Boeing 737; a private aircraft may represent a small personally owned aircraft, like a Cessna. Military targets travel the fastest, followed by commercial, then private. The targets also have a data tag affixed to them which shows the aircraft's call sign consisting of a letter and numerical designator. The military aircraft are designated by the letter "M" for military and one sequential number. The private aircraft are designated by the letters "GA," for "general aircraft," and one sequential number. The commercial aircraft are designated by a 2-letter airline identifier and a random 4-digit number.

The targets will follow one of eight approach paths **[point to each path]** starting at the extreme N, NE, E, SE, S, SW, W, and NW locations and proceeding to one of the two airports. The aircraft will be assigned to land at one of the two airports, named A1 and A2 **[point to them]**, and will be assigned to one of the two airport's runways, R1 or R2.

You will notice 8 small circles on the Multitask display. These depict aircraft holding fixes (or locations at which an aircraft may circle while awaiting clearance to land.) **[Point to them.]** The yellow concentric circles on the radarscope display are each 10nm apart. (This is very important for the situation awareness questions you will need to answer later in the experiment.)

The goal of the task is to contact targets before they reach their assigned airport, and, if needed, assign a clearance change to avoid conflicts with other aircraft. Do you have any question about the display?

[Start MultiTask with ‘Trial: Manual Practice (30min)’, ‘Skill Level: 1’, and ‘Automation: None selected’. Have subject perform each function as it is described.]

I will now explain each control function in Multitask. After explaining each function, I will ask you to perform that function on the simulator. To begin this training session, press “Enter” on the keyboard.

When targets first appear on the display, they are flashing to indicate they have not yet been contacted. You will establish a communication link with flashing targets by double-clicking on the triangle icon with the *left* mouse button, selecting the ‘Query’ button in the command box **[point to box]**, and waiting for the aircraft information to appear in the data box **[point to box]**. Please do this now. **[Wait for processing.]** When there are multiple aircraft, as will be the case in the experiment trials, only one aircraft may be contacted at a time. An aircraft that has been contacted will stop flashing, and will be represented by a steady, white triangle icon. A queried aircraft’s information including its call sign, speed, destination airport, and destination runway **[point to each]** will all be displayed in the blue data box on the top of the control box.

To issue a clearance change to an aircraft that has been contacted, you will double-click on the desired target with the *left* mouse button. Then choose from one of the five clearance changes in the command box **[point to the command box]** and select the ‘Submit’ button. The commands are only requests, and aircraft may not conform to your request. I will now explain each command, and then ask you to perform that command on the display aircraft:

Reduce speed – The reduce speed command is used to slow an aircraft down. An aircraft can only reduce its speed once, and cannot be returned to its previous speed. Please issue a reduce speed command now. Notice that as you perform an operation, the pilot/controller dialog for that operation appears in the history box at the bottom of the command box.

[Point to history box.] This script will let you know if an aircraft is conforming to your request or not. The ‘Cancel’ button may be used to interrupt the processing of a command, but once a command is given, it cannot be changed.

Hold – The hold command is used to request an aircraft to fly directly to the closest of one of the eight holding fixes on the display. Please issue a hold command for the aircraft now.

Notice that when more than two verbal exchanges have occurred in the history box, the history box may be scrolled with the arrow buttons to view previous commands. Please do this now. Once arriving at a holding fix, the aircraft icon will turn yellow. An aircraft will remain at a holding fix until directed to continue to the assigned airport and runway using the ‘Resume’ command. **[Do not have them resume flight yet – use ‘Change airport’.]** An aircraft can only fly to a holding fix if it is outside the 30nm circle on the radarscope display.

[Point to the appropriate ring.]

Change airport – The change airport command is used to request an aircraft to fly to the airport to which it was not originally assigned. This command may only be used when an aircraft is in a holding pattern. Once a change airport command is issued, the aircraft, after a short delay, will proceed to the new airport assignment. Please issue a change airport command for the aircraft now. Note that the aircraft is now flying to the other airport.

Remember that the 'Resume' command may also be used to release an aircraft from a holding fix, but it will then fly to its previously assigned airport.

Change runway – The change runway command is used to request an aircraft to land on a runway (at its assigned airport) to which it was not originally assigned. This command may only be used when an aircraft is in a holding pattern, or inside the 30nm circle. Please issue a change runway command to the aircraft now.

To review **[point to each area]**, outside the 30nm circle, only the reduce speed and hold commands may be given. While at a holding fix, only the resume, change airport, and change runway commands may be given. Inside the 30nm circle, only the change runway and reduce speed commands may be given.

[End the session and keep the performance measures window on the screen.]

Your simulation score will be based on 3 factors: *cleared aircraft, conflicts, and actual collisions*.

-- Cleared aircraft are defined as contacted aircraft arriving safely at an airport.

-- Conflicts are defined as aircraft traveling within 3 nm of other aircraft, or aircraft that are within 20 nm of the radarscope center **[point to the second yellow circle]** destined for the same runway at the same airport.

-- Actual collisions are defined as aircraft that come in contact with each other or simultaneously arrive at the same airport destined for the same runway, in which case auditory feedback is provided and both aircraft are removed from the screen. To prevent

conflicts and *actual collisions*, you are advised to issue changes to the aircraft's randomly assigned clearance.

Your selection of the various clearance changes and which aircraft you apply the changes to will be dependent upon which target you think requires the most immediate attention. All targets should be contacted (not flashing) before they reach an airport. Your efficiency will also be scored as the number of clearance amendments used, and you should attempt to minimize these amendments. Do you have any questions about these performance measures or about the simulation in general?

We will now begin the first of six training sessions.

I ask at this time that you remove your watch from your person and place it in a pocket. Also ensure that your cell phone is turned off. Due to the nature of this experiment, keeping your attention focused on the ATC task is very important.

[Select 'Trial: Manual Practice (30min)', 'Skill Level: 5', and 'Automation: None selected'. Enter subject number, random seed, and a trial number. Do not check the box for 'Run Gauge.']

You will have 10 minutes to practice contacting aircraft and resolving conflicts on the 'radar' scope. You should take advantage of this practice period to formulate a conscious strategy for effectively clearing targets. You may take time to learn the controls and get a feel for the interface, as your performance in this training period will not be recorded.

Feel free to move the keyboard, wrist pad, mouse, and chair around to a comfortable position during training. If you encounter a difficulty during the session please do not hesitate to bring it to my attention, and I will immediately assist you.

Please commence training by depressing the ‘Enter’ key on my mark.

[Stop trial after 10-minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions before beginning the next training sessions?

IV. Gauge-Monitor Training

You will now be provided training in the gauge-monitoring task.

[Turn the gauge-monitoring computer monitor on. Point to all of the ranges as they are described.]

The gauge-monitoring task involves maintaining a moving, white pointer within an ‘acceptable’ green and blue range on a fixed scale display. The pointer moves “up” and “down” the scale in a random manner. You will use the ‘Shift’ key to move the pointer back up into the acceptable range if it drifts into the lower red, ‘unacceptable’ range; or the ‘Ctrl’ key to move the pointer back down into the acceptable range if it drifts into the upper red range. **[Point to the keys.]** Note that the ‘Control’ and ‘Shift’ control keys do not function when the pointer is within the acceptable green and blue ranges.

A ‘Correct Detection’ is recorded by the system when you redirect the pointer after it has drifted into the ‘unacceptable’ range. A ‘False Detection’ is recorded when you attempt to

redirect the pointer when it is in the ‘acceptable’ range. This type of action is counted against you. A ‘Miss’ is recorded when the pointer drifts into the ‘unacceptable’ range without a control action, and will also be counted against you. Do you have any questions about the gauge-monitoring task? **[Select ‘Trial: Manual Practice (30min)’, any skill level, and any automation. Make sure “Run Gauge” is checked. Turn the radarscope monitor off.]**

You will now have five-minutes to practice maintaining the moving pointer within the acceptable range on the fixed scale display. Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the ‘Enter’ key on my mark.

[Stop trial after 5-minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions before beginning the next training sessions?

V. Automation training

We will now begin the automation training sessions. The MultiTask simulation is capable of operating under four different modes of automation in addition to the manual control mode you have already learned. Reference sheets for each mode of automation will be left next to the computer throughout the training sessions if you need to review their functions at any time. You will also be allowed to reference these sheets before each test session, but they will not be available during test sessions. **[Show them the sheets on the desk.]**

Information Acquisition

The first mode is called information acquisition. **[Show the subject this page of the reference sheets.]** This form of automation incorporates a scan line that rotates clockwise around the radar display, and as it passes over an aircraft icon, a Trajectory Projection Aid (or 'TPA') for that aircraft is presented for two seconds. The TPA shows the aircraft route in the form of a line connecting the aircraft and the destination -- either an airport or holding fix. The aircraft speed in knots, destination airport, and destination runway are all affixed to the center of the TPA. If the right mouse button is clicked on an aircraft during the two seconds after the scan line passes an icon, that aircraft's TPA will be displayed for an additional 8-seconds. Do you have any questions concerning the operation of the simulation under information acquisition automation? **[In MultiTask select 'Trial: Automation Practice (30min)', 'Skill Level: 5', and 'Automation: Information Acquisition'. Enter subject number, random seed, and a trial number. Do not check the 'Run Gauge' box.]**

You will now be given 10 minutes to familiarize yourself with this mode of automation.

Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the 'Enter' key on my mark.

[Stop the trial after 10 minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions before beginning the next training session?

Information analysis

The next automation mode is information analysis. **[Show the subject this page of the reference sheets.]** The information analysis form of automation displays information pertinent to each of the contacted aircraft in the automaton aid box **[point to where the aid box will be on the display]** including the aircraft's call sign, destination airport, destination runway, speed, and distance (nm) from the destination airport. A final block, 'Conf,' denotes the call sign of any aircraft that are currently in conflict. The speed block represents the aircraft's speed at its original assigned speed, displayed as 'SPD1', or reduced speed, displayed as 'SPD2'; however, the true aircraft speed can still be obtained from the data box by querying the aircraft. **[Point to the data box again.]** Do you have any questions concerning the operation of the simulation under information analysis automation?

[In MultiTask select 'Trial: Automation Practice', 'Skill Level: 5', and 'Automation: Information Analysis'. Enter subject number, random seed, and a trial number. Do not check the 'Run Gauge' box.]

You will now be given 10 minutes to familiarize yourself with this mode of automation. Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the 'Enter' key on my mark.

[Stop trial after 10-minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions before beginning the next training session?

Decision making

The next automation mode is decision making. **[Show the subject this page of the reference sheets.]** In addition to conflict alerting, decision making automation provides recommendations for resolving aircraft conflicts and displays these recommendations in the automation aid box. The conflicting aircraft IDs, the recommended change (speed, hold, resumption, or airport), and the aircraft to which the clearance should be issued are all displayed together. Up to three recommendations are displayed in the automation aid box at a time and they are listed in order of priority. Runway changes are not prescribed by the decision aid; therefore, you will need to closely monitor aircraft within 30 nm of the airports. Do you have any questions concerning the operation of the simulation under decision making automation?

[In MultiTask select ‘Trial: Automation Practice’, ‘Skill Level: 5’, and ‘Automation: Decision Making’. Enter subject number, random seed, and a trial number. Do not check the ‘Run Gauge’ box. Stop the trial after 10 minutes]

You will now be given 10 minutes to familiarize yourself with this mode of automation. Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the ‘Enter’ key on my mark.

[Stop trial after 10-minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions before beginning the next training session?

Action implementation

The next mode of automation is action implementation. **[Show the subject this page of the reference sheets.]** The action implementation level of automation simulates the hand-off of ATC from approach control (the task you have been performing) to local tower control.

Subsequently, the tower automatically maintains full control and responsibility of all aircraft within 20 nm of the center of the radarscope. You are only responsible for controlling aircraft from the periphery of the radarscope to the 20 nm line. **[Point to the area between the periphery and the 20 nm line.]** Automated control, activated inside this line, prevents any conflicts (either conflicts or collisions). The action implementation automation aid box simply tallies the number of aircraft on the radar display, by type. Do you have any questions concerning the operation of the simulation under action implementation automation?

[In MultiTask select 'Trial: Automation Practice', 'Skill Level: 5', and 'Automation: Action Implementation'. Enter subject number, random seed, and a trial number. Do not check the 'Run Gauge' box. Stop the trial after 10 minutes]

You will now be given 10 minutes to familiarize yourself with this mode of automation.

Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the 'Enter' key on my mark.

[Stop the trial after 10 minutes]

That concludes the training you will receive on the various functions of simulation automation. Do you have any questions about any of the automation functions of MultiTask?

There will now be a 10 min break prior to additional practice sessions. If you need to use the restroom or get a drink, please do so at this time.

[Allow for a 10-min rest period.]

VI. Dual-Task Practice

All experiment trials will include adaptive forms of the previously described modes of automation. Under adaptive automation, your performance on the gauge-monitoring task will dictate whether the computer provides you with assistance in the ATC simulation, or whether you perform the task manually. If you perform poorly on the gauge-monitoring task, automation will be allocated in the simulation, and an ‘Automation is ON’ box will appear in the lower left corner of the display **[point to the automation status box on the computer display]**. Once your performance of the gauge-monitoring task improves, the automation will be turned off, manual control will be returned to you, and ‘Automation is OFF’ will appear in the lower left corner of the display.

In this practice session, you will perform both the gauge-monitoring task and the ATC simulation. As in the other practice sessions, your tasks will be to contact, clear, and safely land all of the aircraft on the display while maintaining the moving gauge pointer in the acceptable range on the fixed scale display. You should focus your attention on the ATC simulation, and attend to the gauge monitor only to the extent that you can. The practice session will last 25 minutes. Your performance during this trial will be recorded, so accuracy is very important.

[In MultiTask select ‘Trial: Dual Task Practice’, ‘Skill Level: 7’, and ‘Automation: <Depending on random assignment – see Freeze Times table>’. Enter subject number, random seed, and a trial number. Make sure ‘Run Gauge’ is checked. Enter a benchmark gauge performance of ‘1’ and a benchmark standard deviation of ‘0’.]

Do you have any questions about the adaptive automation function of MultiTask?

You will operate the simulation under adaptive automation of the <see Freeze Times table> mode of automation. Do you have any questions about his mode of automation? **[If the subject does, allow them to review the appropriate reference sheet.]**

Please commence testing by depressing the ‘Enter’ key on my mark.

[While the trial is running, open the ‘Login’ form on the SAGAT database. Log the subject on, and open SAGAT questions 1, 7, and 13. Place a SAGAT questionnaire key on the desk.]

[Stop the trial after 25 minutes. Once training is complete, offer an optional 2-min rest period.]

If you need to use the restroom or get a drink, feel free to take a 2-minute break at this time.

Do you have any questions about the adaptive automation function of MultiTask?

VII. SAGAT

You will now be given training on the Situation Awareness Global Assessment Technique, or ‘SAGAT’. The SAGAT involves a series of questionnaires presented during the simulation that are intended to assess your knowledge of the current and future simulation status. Each experiment trial will include three stops, or ‘freezes’, and during each freeze you will respond to 6 SAGAT questions. At random times during test trials, the Multitask simulation

will freeze and the display screen will be minimized. You will not be able to acquire any more information on the simulation from the monitors during a freeze. You will then turn your chair to the secondary computer and immediately complete the SAGAT questionnaire key that will be on the desk. **[Show the subject the questionnaire key.]** This is a form that you will use as a basis to answer all of the SAGAT questions. You will be asked to indicate where the 7 aircraft are currently located by randomly assigning a number 1-7 to each aircraft and writing that number at the aircraft's corresponding location on the graphic. You will then begin completing the electronic SAGAT forms that are open on the secondary computer display. This is what the forms will look like. **[Point to the forms that are open on the computer display.]** Each form will ask a question about all 7 aircraft, and you are required to provide an answer for each aircraft based on the numbers you assigned the aircraft.

Some questions will ask about the headings of aircraft. These questions will be accompanied by a diagram of a compass for your reference. The up, or North, direction from the aircraft corresponds to 360 degrees; the right, or East direction from the aircraft refers to 90 degrees; and so on. **[Show subjects on the display, and use the questionnaire key graphic if needed.]** Your answers for these questions will be numerical (between 1 and 360 degrees). Other questions may ask you for speeds, distances, aircraft call signs, and other information that can be gathered from the simulation display. If needed, a criterion will be presented on the bottom of the form which identifies how accurate your answer must be.

While you are answering the questions, I will reactivate the simulation monitors in order to record the actual state of the Multitask simulation. It is imperative that you do not look at the

monitors while answering the questions. If you do look at the monitors during a SAGAT freeze, this will be considered as cheating and you will be immediately removed from the experiment. Do you have any questions about any of the SAGAT procedures?

This SAGAT training session involves you looking at three example questions using the SAGAT application interface. When you are done looking at a question, press the “Next” button to view the next question until there are no more questions. Take 5-minutes to look over the questions, and ask any questions you may have about the format and content of the questions. You may begin.

[While subject is reviewing the questions, save the GPRAC.txt file to disk.]

[Once training is complete, require a 5-min rest period.] There will be a 5 min break prior to beginning the next practice period. If you need to use the restroom or get a drink, please do so at this time

[During the break, import the GPRAC.txt file into excel. Calculate the mean and standard deviation for the last 20 minutes of the dual task practice. Record the values on the front cover of the subject’s folder.]

VIII. Dual-Task and SAGAT Practice

You will now be provided one more practice trial, similar to the previous dual-task practice; however, in this trial you will experience three SAGAT freezes. As in the other practice sessions, your tasks will be to contact, clear, and safely land all of the aircraft on the display while maintaining the moving gauge pointer in the ‘acceptable’ range on the fixed scale display. Remember, you should focus your attention on the ATC task and attend to the

gauge monitor whenever you can. The simulation will also be stopped at random points in time, and you will be required to answer SAGAT questions as accurately as possible. This practice session will last 30 minutes. This session is representative of the experiment test trials in that the aircraft speeds will be realistic given the distances presented on the radar scope. Unless you have any questions, we will begin the training session. Your performance during this trial will be recorded, so accuracy is very important.

[In MultiTask select ‘Trial: Experiment Trial’, ‘Skill Level: 7’, and ‘Automation: <Depending on random assignment – see Freeze Times table>’. Enter subject number, random seed, and a trial number. Make sure ‘Run Gauge’ is checked. Enter the performance data calculated during the break.]

Please commence testing by depressing the ‘Enter’ key on my mark. **[Start the timer for the time listed on the Freeze Time table. Place a questionnaire key at the secondary desk. When the timer goes off, immediately press the ‘Q’ and ‘B’ keys on the keyboard.]**

Please turn your chair to the secondary desk, and complete the questionnaire key. **[While subjects are completing the key, log the subject into the SAGAT interface using the appropriate automation status – manual or automation. Select the random questions for that trial.]** Now answer the questions that are open on the SAGAT interface. Continue to the next question until there are no more questions left to answer. Remember, do not look at the simulation display while answering SAGAT questions, or you will be terminated from the experiment.

[Click on the Multitask action bar, and press the ‘V’ key to maximize the display. Answer the random questions on the SAGAT Answer Sheet using the subject’s

questionnaire key. Press the 'B' key again, and wait for the subject to finish. When subject is finished, and repositioned at the primary simulation display, maximize the display and restart the simulation using the 'V' and 'R' keys.]

[Repeat SAGAT procedures for remaining 2 stops.]

[Stop the trial after 30 minutes]

That concludes your participation for the first day of the experiment. Do you have any questions about the applications you have learned today? **[Enter the time and payment amount on the payment form.]** Please look over the payment form closely and initial by the 'Finish Time', 'Total Time', and your earned pay for today's participation. The next two days of your participation will last more than 5 hours each, so please come well rested.

[Discuss the starting date and time for the second and third day of participation, and remind them to please be on time.]

[Before the second day, import the GTEST.txt gauge data from the last practice session into Excel. Calculate the mean and standard deviation for gauge performance during the last 20 minutes. Record these figures, and average them with the data from the other subject assigned the particular mode of automation. Use the average mean performance and standard deviation as a basis for triggering AA in all test trials with that mode of automation.]

Days 2 & 3

[Welcome the subject back. Remind the subject to turn their cell phone off. Record the date and exact time in the ‘Date’ and ‘Start Time’ blocks on the Payment Form. Ask the subject to initial the two blocks. Place the “Experiment in Progress” sign on the door.]

IX. Review

A brief review session will be conducted to remind you of the application functions you will use today. Please follow along on the MultiTask automation reference sheets.

[In MultiTask select ‘Trial: Experiment Trial’, ‘Skill Level: 7’, and ‘Automation: none’. Enter subject number, random seed, and a trial number. Check the ‘Run Gauge’ box. Enter a benchmark gauge performance of ‘1’ and a benchmark standard deviation of ‘0’.]

Remember, the goal of the task is to contact targets before they reach their assigned airport, and, if needed, assign a clearance change to avoid conflicts with other aircraft. The following clearance changes may be administered: reduce speed, hold, resume, change runway, and change airport. Outside the 30nm circle, only the reduce speed and hold commands may be given. While at a holding fix, only the resume, change airport, and change runway commands may be given. Inside the 30nm circle, only the change runway and reduce speed commands may be given. Aircraft must be queried before reaching an airport. Performance measures include cleared aircraft, conflicts, actual collisions, and clearance amendments.

Your goal in the gauge-monitoring task is to keep the moving pointer within the green and blue 'acceptable' range using the 'Shift' and 'Ctrl' keys. The ATC simulation display should always be your priority, and you should focus your attention to the gauge-monitoring task only when you can. Do you have any questions about the gauge-monitoring task?

You will now be given 10 minutes to re-familiarize yourself with the simulation. Your performance during this trial will not be recorded, so please feel free to ask any questions you may have during the trial.

Please commence testing by depressing the 'Enter' key on my mark.

[Stop the trial after 10 minutes. Do not write data to file.]

Remember that the simulation can operate under four different modes of automation. **[Show the subject the automation reference sheets.]** These modes include:

Information Acquisition. A scan line rotates clockwise around the radar display, and as it passes over an aircraft icon, a Trajectory Projection Aid (TPA) for that aircraft is presented for two seconds. The TPA shows the aircraft route in the form of a line connecting the aircraft and the destination -- either an airport or holding fix. The aircraft speed (in knots), destination airport, and destination runway are affixed to the center of the TPA. If the right mouse button is clicked on the aircraft during the two seconds after the scan line passes it, the TPA will be displayed for an additional 8-seconds. No information is displayed in the automation aid box. All other functions of the simulation operate as in the manual control mode.

Information Analysis. Information pertinent to each of the aircraft on the radarscope is displayed in the automation aid box including the aircraft's call sign, destination airport, destination runway, speed, and distance (nm) from the destination airport. A final block, 'Conf,' denotes the call sign of any aircraft that are currently in conflict. All other functions of the simulation operate as in the manual control mode.

Decision Making. In addition to conflict alerting, recommendations for conflict resolution are provided in the automation aid box. The identities of the conflicting aircraft, the recommended change (speed, hold, resumption, or airport), and the aircraft to which the clearance should be issued are all displayed together. Up to three recommendations are displayed in the automation aid box at a time and they are listed in order of priority. Runway changes are not prescribed. All other functions of the simulation operate as in the manual control mode.

Action Implementation. This level of automation simulates the hand-off of aircraft control from approach control to local tower control. The tower automatically maintains full control and responsibility of all aircraft within 20 nm of the center of the radarscope. Automation within this area prevents any conflicts after the hand-off to tower control occurs. The action implementation automation aid box displays a tally of aircraft on the display by type. All other functions of the simulation operate as in the manual control mode.

Do you have any questions about the ATC simulation functions?

Finally, the simulation will be stopped at random times prompting you to fill out the SAGAT Questionnaire Key and answer the SAGAT questions on the secondary computer interface.

If you look at the active simulation display while answering SAGAT questions, you will be terminated from the experiment. Descriptions of the SAGAT questions are next to the computer screen for you to review during SAGAT stops.

Do you have any questions about the SAGAT questionnaires?

Do you have any questions about any of the applications you will use in the test sessions?

Before each test session you will be allowed to review the reference sheets for that particular mode of automation to be tested, but you may not review the reference sheets during a testing session.

If you don't have any more questions, we will begin the testing portion of the experiment.

X. Testing

Experiment testing will occur in a manner similar to the last practice session on Day 1.

Adaptive automation will be applied to the ATC simulation, involving one of the four modes of automation. Each trial will incorporate one mode of automation, control will shift between manual and automated assistance depending upon your gauge task performance, and SAGAT freezes will occur. Each trial will last 30-minutes and you will be offered a break after every trial. Your performance during all of the trials today will be recorded, so accuracy is very important. Do you have any questions about the experiment trial procedures?

Trial <see 'Mode Order' reference sheet>

This trial will incorporate the <see 'Mode Order'> mode of automation. You will now be allowed to review the functions of that mode of automation. **[Allow subject to review the appropriate automation reference sheet that is on the desk near the computer. Wait. Subsequently, file it until the next test trial.]**

This trial will last 30 minutes. If you encounter a difficulty during the session please do not hesitate to bring it to my attention, and I will immediately assist you.

[In MultiTask, select 'Trial: Experiment Trial', 'Skill Level: 7', and 'Automation: <see 'Mode Order'>'. Enter subject number, random seed, and trial number. Make sure the 'Run Gauge' box is checked. Enter the average gauge performance and standard deviation values captured during the dual-task with SAGAT session.]

Unless you have any questions, we will begin testing.

Please commence testing by depressing the 'Enter' key on my mark. **[Start the timer for the time listed on the Freeze Time table. Place a questionnaire key at the secondary desk. When the timer goes off, immediately press the 'Q' and 'B' keys on the keyboard.]**

Please turn your chair to the secondary desk, and complete the questionnaire key. **[While subjects are completing the key, log the subject into the SAGAT interface using the appropriate automation status – manual or automation. Select the random questions for that trial.]** Now answer the questions that are open on the SAGAT interface. Continue to the next question until there are no more questions left to answer. Remember, do not look at the simulation display while answering SAGAT questions, or you will be terminated from

the experiment. Descriptions of the SAGAT questions are next to the computer screen for you to review during SAGAT stops.

[Click on the Multitask action bar, and press the ‘V’ key to maximize the display.

Answer the random questions on the SAGAT Answer Sheet referencing the subject’s questionnaire key for aircraft numbers. Press the ‘B’ key again, and wait for the

subject to finish. When subject is finished and repositioned at the primary simulation display, maximize the display and restart the simulation using the ‘V’ and ‘R’ keys.]

[Repeat SAGAT procedures for remaining 2 stops. The trial will end after 30 minutes.

Be certain to write data to file.]

[Allow for a 10-minute break.]

There will now be a 10 min break prior to beginning the next trial. If you need to use the restroom or get a drink, please do so at this time.

[Repeat procedures for each trial.]

XI. Conclusion

I’d like to thank you for your participation. Again, this research is funded by NASA and will help in designing ATC systems in the future. I can now answer any questions you have about the experiment.

Closing Questionnaire

[Give the subject the closing questionnaire.] Please take a few minutes to answer these questions. If you have any questions, feel free to ask.

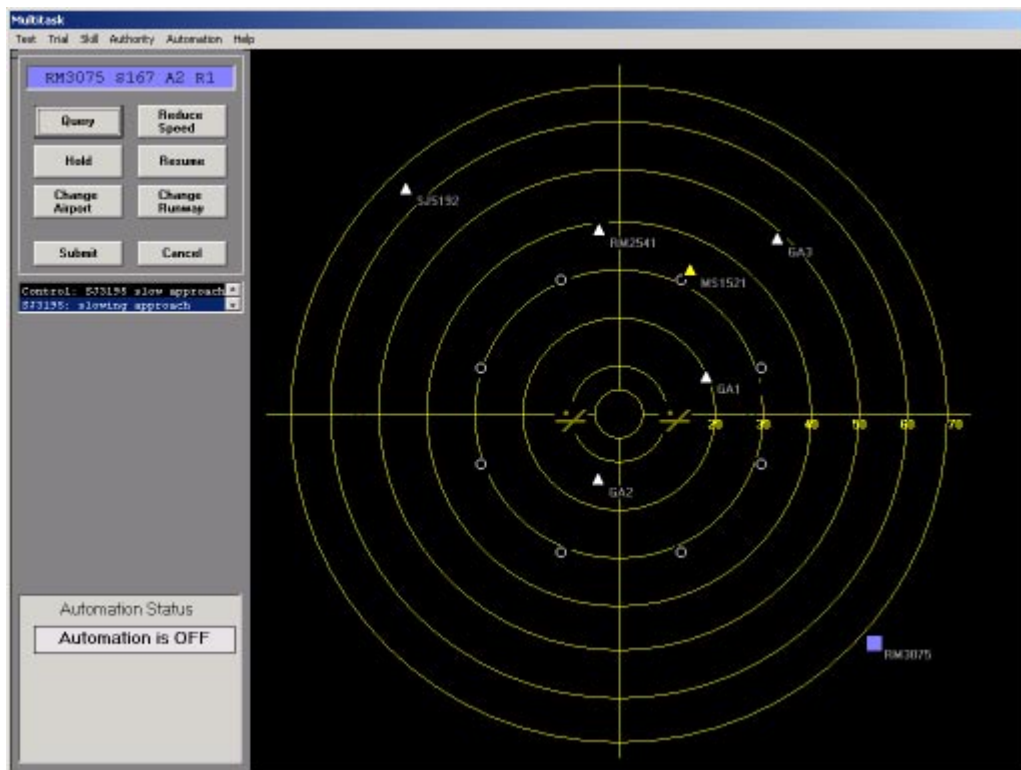
[Enter the time and payment amount on the payment form. Sign the form as the experimenter.] Please look over the payment form closely and initial by the finish time, total time, your earned pay for today's participation, and the total pay earned for the experiment. You will need to take this form to Mrs. Sankaran in the IE department, room 331c, within the next two weeks. She will pay you cash for your participation. I will contact you if you have won the contest based on your scores. Thank you.

[Import the multitask and gauge-monitoring task performance measures into Excel. Grade all SAGAT responses and import data. Enter combined score on contest sheet. Clean room, and file subject folder.]

Level of Automation Definitions

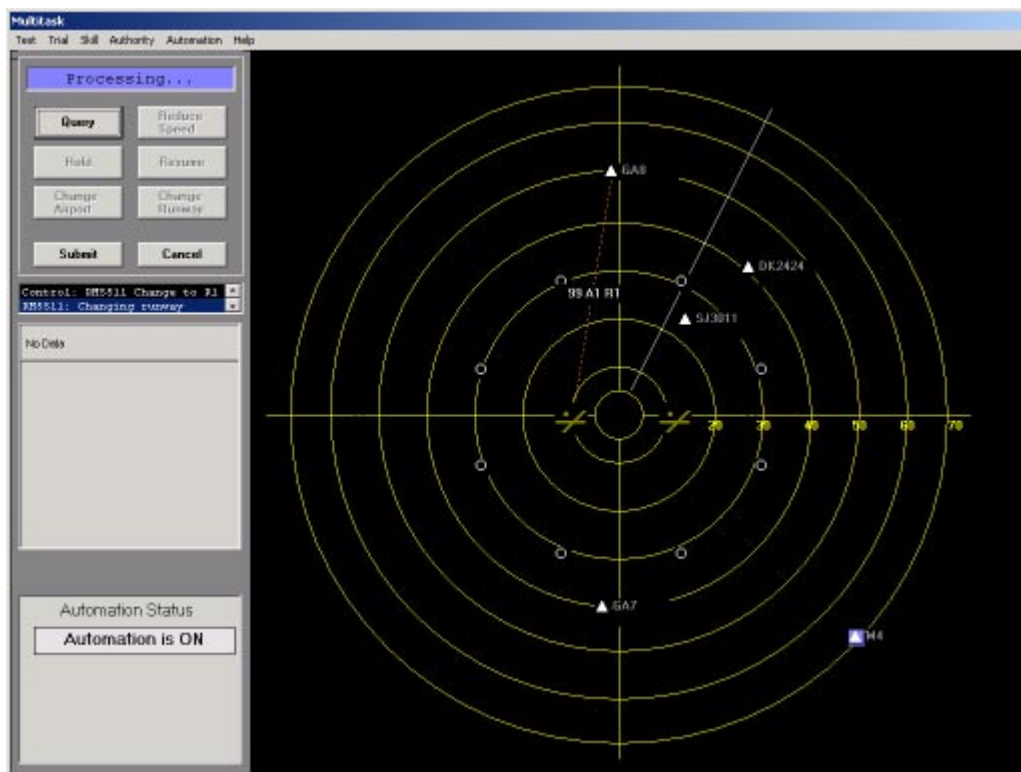
Manual control

No additional assistance is provided.



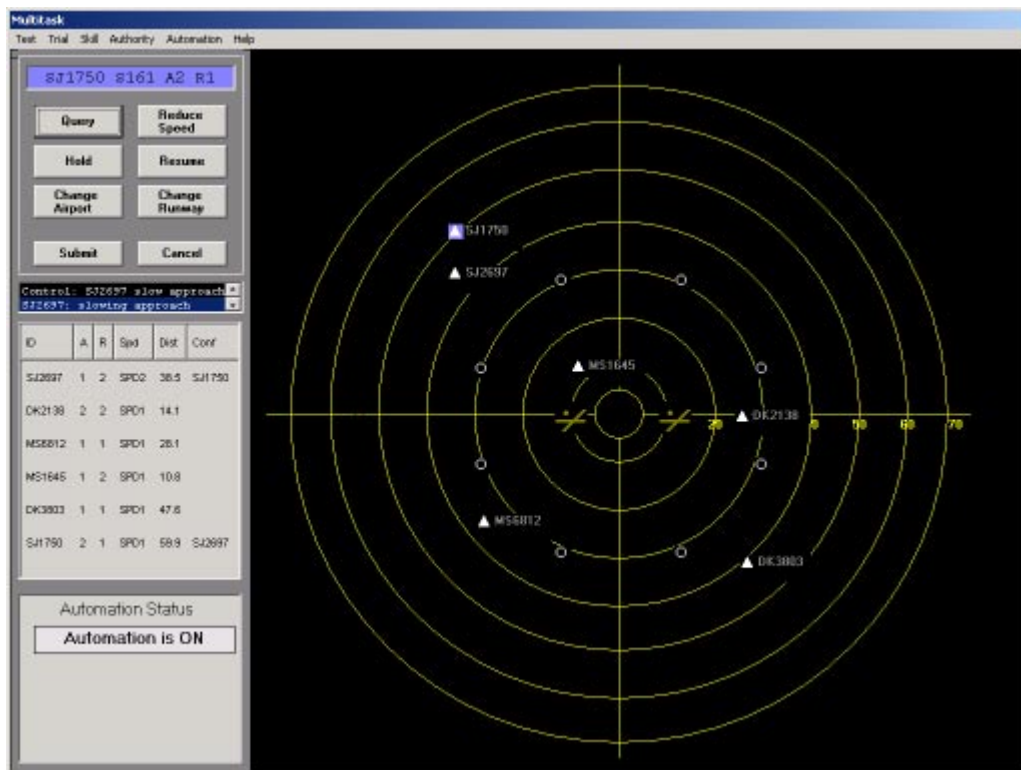
Information acquisition

A scan line rotates clockwise around the radar display, and as it passes over an aircraft icon, a Trajectory Projection Aid (TPA) for that aircraft is presented for two seconds. The TPA shows the aircraft route in the form of a line connecting the aircraft and the destination -- either an airport or holding fix. The aircraft speed (in knots), destination airport, and destination runway are affixed to the center of the scan line. If the right mouse button is clicked on the aircraft during the two seconds after the scan line passes it, the TPA will be displayed for an additional 8-seconds. No information is displayed in the automation aid box. All other functions of the simulation operate as in the manual control mode.



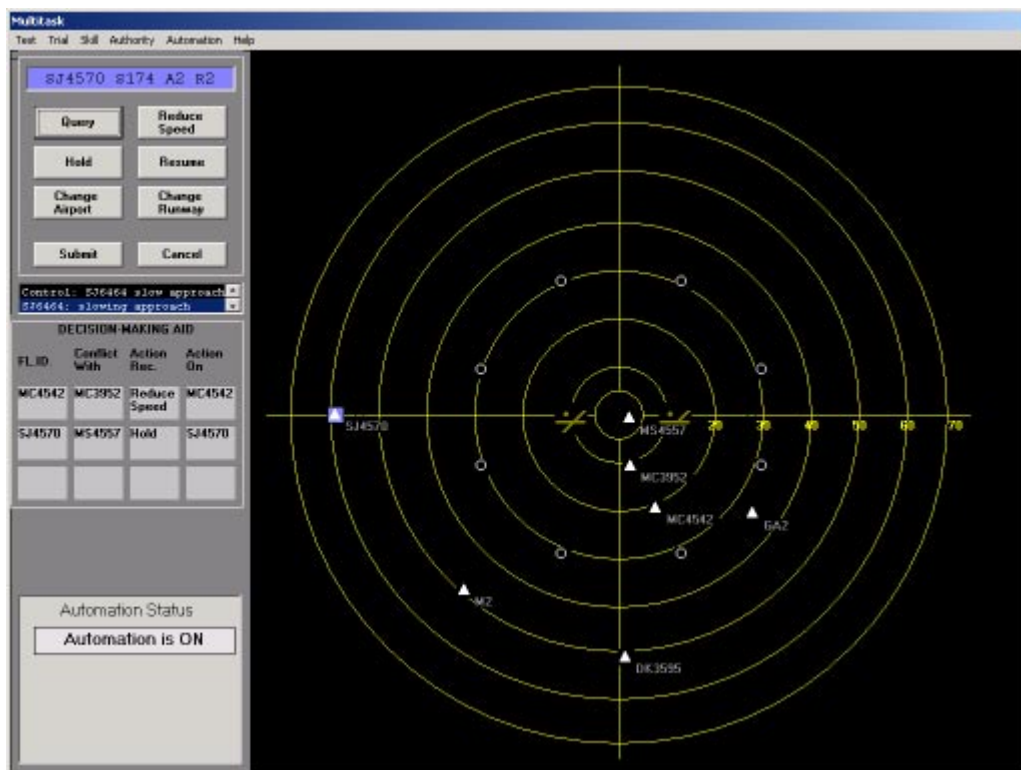
Information analysis

Information pertinent to each of the contacted aircraft on the radarscope is displayed in the automaton aid box including the aircraft's call sign, destination airport, destination runway, speed, and distance (nm) from the destination airport. A final block, 'Conf,' denotes the call sign of any aircraft that are currently in conflict. All other functions of the simulation operate as in the manual control mode.



Decision making

In addition to conflict alerting, recommendations for conflict resolution are provided in the automation aid box. The identities of the conflicting aircraft, the recommended change (speed, hold, resumption, or airport), and the aircraft to which the clearance should be issued are all displayed together. Up to three recommendations are displayed in the automation aid box at a time and they are listed in order of priority. Runway changes are not prescribed. All other functions of the simulation operate as in the manual control mode.



Action implementation

This level of automation simulates the hand-off of aircraft control from approach control to local tower control. The tower automatically maintains full control and responsibility of all aircraft within 20 nm of the center of the radarscope. Automation within this area prevents any conflicts after the hand-off to tower control occurs. The action implementation automation aid box displays a tally of aircraft on the display by type. All other functions of the simulation operate as in the manual control mode.

