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Modeling distributed cognition : system interaction in free flight

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MODELING DISTRIBUTED COGNITION:
SYSTEM INTERACTION IN FREE FLIGHT

A Thesis

Presented to

The Faculty of the Department of Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Brian F. Gore

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ABSTRACT

MODELING DISTRIBUTED COGNITION: SYSTEM INTERACTION IN FREE FLIGHT

By Brian F. Gore

This thesis addresses the critical topic of free flight; the concept aimed at increasing system capacity and air traffic services to improve accessibility, flexibility, and predictability in the national airspace in order to reduce flight times, crew resources, maintenance, and fuel costs. An evaluation of behavioral and system costs associated with current day and free flight operations was performed using two First Principles models, Air Man-machine Integration Design and Analysis System (Air MIDAS) and the Integrated Performance Modeling Environment (IPME). Both tools revealed increases along a seven-point, four-channel workload scale from current day ($\underline{M}_{\text{Air MIDAS}} = 0.77$, $\underline{M}_{\text{IPME}} = 1.24$) to free flight conditions ($\underline{M}_{\text{Air MIDAS}} = 1.15$, $\underline{M}_{\text{IPME}} = 1.96$). The inclusion of a handoff and an emergency was found to differentially affect the workload levels of the operators. The models provided different performance profile predictions depending on the operator's role associated with this system change. These findings support the notion of initially using models for variable inclusion in costly simulation studies.

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My wife, Becky Hooey, contributed significantly to my successes in graduate school. She was responsible for motivating and supporting my research interests throughout my education experience. Finally, I would like to thank my parents who instilled the value of knowledge and comprehension necessary for success.

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Abstract

The Federal Aviation Administration (FAA) has established the strategic goal for System Capacity and Air Traffic Services to improve accessibility, flexibility, and predictability in the national airspace in order to reduce flight times, crew resources, maintenance, and fuel costs through a concept known as free flight. An evaluation of behavioral and system costs associated with current day and free flight operations was performed using two First Principles models, Air Man-machine Integration Design and Analysis System (Air MIDAS) and the Integrated Performance Modeling Environment (IPME). Both tools revealed increases along a seven point, four channel workload scale from current day ($\underline{M}_{\text{Air MIDAS}} = 0.77$, $\underline{M}_{\text{IPME}} = 1.24$) to free flight conditions ($\underline{M}_{\text{Air MIDAS}} = 1.15$, $\underline{M}_{\text{IPME}} = 1.96$). The inclusion of a handoff and an emergency was found to differentially affect the workload levels of the operators. The models provided different performance profile predictions depending on the operator's role associated with this system change. These findings support the notion of initially using models for variable inclusion in costly simulation studies.

Modeling Distributed Cognition: System Interaction in Free Flight

The world community of aviation operations is engaged in a vast, system-wide evolution in human/system integration. The nature of this change is to relax restrictions in air transport operations wherever it is feasible. A new air traffic management concept, known as free flight, has recently been proposed that relaxes the rigid airway structure and in-trail spacing of aircraft (RTCA, 1995). This air traffic management system established by the Federal Aviation Administration (FAA) has the strategic goal for System Capacity and Air Traffic Services to improve accessibility, flexibility and predictability in the aviation system (RTCA, 1995). The relaxation includes schedule control, route control, and, potentially, separation authority in some phases of flight, for example aircraft self-separation in enroute and oceanic operations. The restrictions that are imposed on the aviation system have been made in order to assure a controlled regimented environment. It is through control that safety has been defined. The only way to achieve safety is through control. It is when one transitions from such a safe operating environment to a potentially less safe operating environment as a result of the decrease in regimented control that a concern arises. This concern is heightened when consideration is given to the consequences of an unsafe aviation system.

Under the current air traffic control (ATC) system, responsibility for heading, altitude, and velocity reside with the ATC (RTCA, 1995). ATC is responsible for detecting and alerting the aircraft of potential conflicts and recommending appropriate resolutions to the conflict situations (Wickens, Mavor, Parasuraman, & McGee, 1998). Under one operational concept of the proposed free flight system, pilots will be responsible to self-separate vertically, horizontally, and laterally with the assistance of automated predictive systems (RTCA, 1995). Predictive displays will provide information about impending conflict situations and the resolution to the conflict situation via alerting logic (Kuchar & Yang, 1997) and visual displays in the cockpit (Johnson, 1998). The rules associated with the transition from an air traffic controlled environment to a free flight operating environment have not yet been clearly established. Wickens et al. (1998) indicate that rules for a free flight environment will need to go beyond the current FAA minimum guidelines to maintain traffic in sight, yield to the aircraft on the right, or to turn to the right to avoid a conflict.

Free Flight Systems

The complex interaction that exists between automated systems and human operators, such as the visual displays required and the accompanying alerting logic, which will undoubtedly accompany the move towards a free flight environment, is not the only area of concern. In fact, there needs to be a consideration of the interactions between the flight crew system in the air and the air traffic control (ATC) system on the ground. Not only are the operators of each system working in significantly different environments separated geographically by potentially thousands of miles, the operators are working vastly different systems that must be coordinated into one single system in a safe and timely manner (Shaffer & Baldwin, 1997). The study of the interactions between the two segments of the system is referred to as the study of distributed cognition (Kirlik, 1995). A functional analysis of both systems in terms of technological, cognitive, social, and organizational aspects is the primary interest when determining the coordination of two vastly different operating systems (Kirlik & Bisantz, in press; Kirlik, 1995).

The reduction in the airway structure as proposed by free flight, will certainly increase the complexity associated with detecting and resolving conflicts between aircraft (Kuchar & Yang, 1997). This occurs because the resolution responsibility is being brought to the cockpit thus changing the nature of the tasks that are engaged in by both the air traffic control system and the flight deck system. As a result of this increased complexity, automated conflict detection and decision aiding systems will be required (Kuchar & Yang, 1997). Automated decision aiding systems often change the nature of the complex tasks that face the operator such as nuclear power plant operation (Moray, Sanderson, & Vicente, 1992) and management of automated cockpits (Sarter & Woods, 1991). Much of nuclear power plant and aviation Human Factors research has been focussed around studying workload and situation awareness. Workload is the amount of attention-demanding work (IPME, 1998). Situation awareness is defined as the comprehension and perception of the present state of the system, and projection of the system's future action (Endsley, 1997).

The addition of automated decision aids that do not provide predictive information, although mostly beneficial, may also have negative impacts on human operator performance (Degani, Shafto, & Kirlik, 1996; Palmer, 1995). In some forms, automated decision aiding systems in nuclear power research (Moray et al., 1992) and aviation research (Wickens, 1992; Sarter & Woods, 1991) have been found to increase workload, decrease operators' situation awareness, interfere with decision-making capabilities, and increase error rates. One reason proposed for this increased difficulty for the human operator is that the use of these automated systems changes the role of the human operator from one of active controller to one of monitor of system components

(Shaffer & Baldwin, 1997). This is a role that is ill suited for the human (Parasuraman, 1997; Sheridan, 1992). The above factors interact in some complex way to create an almost impossible task for the normally "adaptable" human being (Shaffer & Baldwin, 1997). In order to develop an accurate understanding of the impact of the transition to free flight, a detailed understanding of the tasks that are performed by the ATC on the ground and the flight crew in the air during conflict detection and resolution is required.

Automated decision aiding systems that make use of predictive information have been found to decrease workload, increase situation awareness, enhance decision making, and decrease error rates (Wickens, 1992). This occurs because information sampling and attention switching becomes somewhat more optimal. Both ground and flight crew will be provided with automated decision aiding systems (RTCA, 1995). The ground crew will use predictive displays that also provide some degree of resolution advisory information called the User Request and Evaluation Tool (URET) and the Display Suite Replacement (DSR). The flight deck will also use predictive displays possessing some degree of resolution advisory information called the Cockpit Display of Traffic Information (CDTI). These technologies will be a requirement as the transition towards a cockpit controlled, ATC-monitored system unfolds. These technologies will be vital as the reduction in airway structure has the potential of increasing airspace conflicts.

Conflict Detection: Current Day Tasks

In the current air traffic control system, the ATC is responsible for detecting and alerting the aircraft of potential conflicts and recommending appropriate resolutions to the conflict situations (Wickens et al., 1998). Air traffic controllers currently have the responsibility to take the initiative to resolve any conflict between aircraft. Conflict situations occur when the safety envelope surrounding an aircraft is compromised. The safety envelope in en route conditions is currently five nautical miles horizontally with 1000/2000 feet vertical separation depending on direction. Controllers follow characteristic steps to deal with a conflict when the airspace is under their control. In the en route situation, ATC need to indicate to the flight crew when two aircraft are within 20 nautical miles of each other (Illman, 1993). If the controller fails to initiate the conflict resolution by this time and an airspace incursion becomes imminent, an alert is triggered that indicates to the controller that a resolution is required (RTCA, 1995). Alternatively, the flight crew can also initiate a resolution. Rarely is the flight crew responsible for identifying and notifying the ATC of a potential conflict. When this happens however, the flight crew is first responsible for determining through the assistance of the ATC the location and direction of the conflict aircraft (Wickens et al., 1998). Once this has been determined, the flight crew indicates to the ATC the flight plan that they are following. The ATC has the responsibility of indicating to the aircraft the heading, speed or altitude change required for resolving the conflict. Prior to any change in flight plan, the flight crew must request a change from the ATC and the controller needs to accept the flight plan change. Once a change is made to the flight plan, the ATC must update the flight plan, and communicate this information to other ATC. Generally speaking however, the flight crew waits for the air traffic controller to guide the actions in the air.

Conflict Detection: Free Flight Tasks

Under one operating mode in the proposed free flight system, pilots will be responsible to self-separate vertically, horizontally, and laterally with the assistance of automated predictive systems (RTCA, 1995). During the free flight rules of travel the controller will need to monitor the air traffic for possible incursions. RTCA (1995) speculates that the safety envelope surrounding an aircraft can safely be reduced to three nautical miles with a 2000 feet vertical separation depending on direction. This ATC role change from an active controller of the airspace to a passive monitor of the airspace will change the ATC actions when dealing with potential conflicts. Upon perceiving an apparent conflict situation, the ATC will monitor the airspace closely to make sure the flight crew makes the appropriate actions to resolve the potential conflict. The ATC will not intervene until they perceive that the flight crew is not going to take the appropriate action in the required time.

Previous research on free flight (Cashion et al., in press; Lozito, McGann, Mackintosh, & Cashion, 1997) has found that there are characteristic steps that are followed by the flight crew when dealing with a conflict situation under free flight operations. The steps that are followed by the flight crew during a free flight conflict resolution include monitoring their display and detecting possible conflicts. An alerting logic with a number of levels of increasing intensity is triggered if the aircrew fail to detect and resolve a conflict. Once the alerting logic has been triggered, the flight crew must contact the conflicting aircraft to attempt to resolve the conflict situation (a maneuver). This occurs in the transgression zone. The non-transgression zone alerts are closer to the aircraft's protected zone and are normally the higher level of alert. These alerting zones including the current day TCAS are shown in Figure 1. Figure 2 outlines the perimeter of the alerting logic zones with reference to aerodynamic and human performance constraints (Corker, 1998). Once there has been the resolution of the conflict, the flight crew may contact the controller (Cashion et al., in press; Lozito et al., 1997). Often times the ideal successful resolution of the conflict in free flight needs little intervention by the ATC in this proposed free flight implementation.

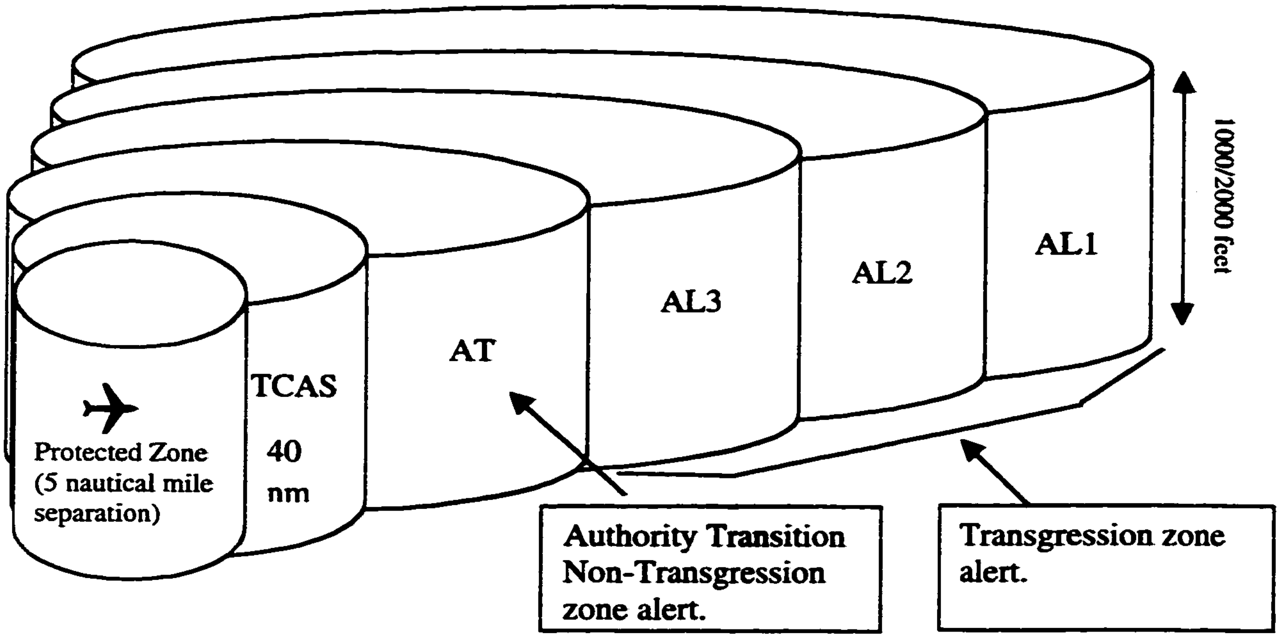
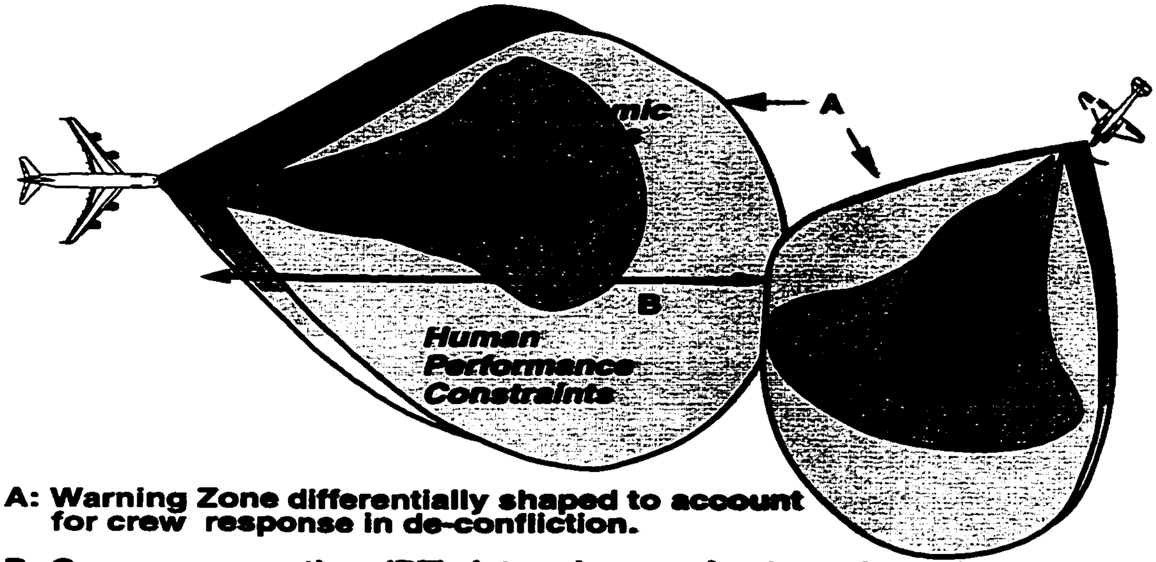


Figure 1. Alerting Logic (AL) Zones (adapted from Lozito et al., 1997). An alerting logic with a number of levels of increasing intensity is triggered if the aircrew fail to detect and resolve a conflict. Once the alerting logic has been triggered, the flight crew must contact the conflicting aircraft to attempt to resolve the conflict situation (a maneuver). This occurs in the transgression zone. The non-transgression zone alerts are closer to the aircraft's protected zone and are normally the higher level of alert. The final alert zone is the Traffic Collision and Avoidance System (TCAS) and is notified auditorally to the flight deck.



A: Warning Zone differentially shaped to account for crew response in de-confliction.

B: Crew response time (RT) determines perimeters of warning/alert zones:

RT= Σ (Perception t) (Decision t) (Communication t) (Neuromotor Response t) / modulation function of intent (expected (+) unexpected (-))

C: Defined by minimum reaction time, similar to TCAS Resolution Alert

Figure 2. Warning Zones and Operator Constraints (from Corker, 1998). These are the warning zones associated with the alerting logic for free flight. The outer zone is the outer warning zone that is differentially shaped to account for speed and heading variation characteristic of conflicting aircraft. The middle zone is the crew response zone that contains the response times of the human performer and the inner zone represents the minimum response zone, similar to the Traffic Alert and Collision Avoidance System (TCAS).

Previous research (Laudeman, Shelden, Branstrom, & Brasil, 1998; Lozito et al., 1997; Endsley, 1997; Wyndemere, 1996) has determined that the implementation of free flight rules of operations greatly affects air traffic controllers' workload and situation awareness. The ATC are subject to workload increases as a result of the reduction of active ATC control over the airspace (Lozito et al., 1997). This reduction in control is further affected by increases in traffic density in the surrounding airspace (Laudeman et al., 1998; Lozito et al., 1997; Wyndemere, 1996). Previous research has studied two groups of ambient traffic, heavy traffic defined as fifteen aircraft and light traffic, defined as eight aircraft, traveling in the surrounding environment (Cashion et al., in press; Lozito et al., 1997; Cashion, Mackintosh, McGann, & Lozito, 1997). The reduction in control has mainly been attributed to the dynamic nature of free flight (Laudeman et al., 1998; Wyndemere, 1996). Endsley (1997) discovered that free flight leads to a reduction in controller situation awareness. Endsley (1997) further discovered that increases in traffic density led to a further reduction in controller situation awareness.

In summary, the concept of free flight as outlined by RTCA, Inc (1995) requires there to be significant changes to the manner in which the system of air travel functions. Many of these changes will impact the human operator. The human operator will be dealing with advanced technologies which will impact flight deck performance as well as ground crew performance because of the different tasks that are involved and because of a change in the nature of the task. Further, the development and use of advancing technologies into a complex operating environment has the potential impact of affecting the stability of a complex system, the stability of a complex system's interaction with another complex system, and potentially impacting the human operator's physical actions in the system. It is for this reason that there has been the development and use of human performance modeling tools. A number of human performance modeling tools have been designed that are aimed at supporting the development of automated systems through evaluation of human performance costs that are associated with increasing technologies. Human performance models are developed and used to test new and potentially hazardous concepts in a safe environment.

Human Performance Modeling

The use of full mission or high fidelity simulation has been used as a method to examine human-systems performance in a safe environment (Campbell et al. 1997). These techniques have proven to be successful in accomplishing the goal of safely and realistically evaluating human behavior in systems but have the disadvantage of being very costly (the cost often times prohibiting their use) (Lee, 1998; Sheridan, 1997). In addition, they cannot test very dangerous situations due to ethical considerations. Modeling is a safer alternative to these expensive simulators in that modeling can be used at an earlier process in the development of a product, system or technology. Human performance modeling tools also avoid the dangers associated with incorporating new technologies by examining human behavior based on empirical data from past human performance that is incorporated within the human performance modeling software (Laughery & Corker, 1997). Since the human operator responsible for interacting in these systems is not present in the actual system evaluation, the risks to the human operator and the costs associated with system experimentation are greatly reduced: no experimenters, no subjects and no testing time.

Human Performance Model Background

Human performance modeling is by no means a new technology. It was introduced over 50 years ago with quasi-linear and manual control models (Craik, 1947; Tustin, 1947). Human performance modeling in these times was related to modeling human tracking behavior in a closed-loop person-machine system (Craik, 1947). These models were termed quasi-linear as the models were derived from an engineer's assumption that the operator's control behavior in perceiving an error and translating this error to a response can be modeled as a linear transfer function. This error is only an approximation of linear behavior and thus has been designated as quasi-linear (Wickens, 1992). In performing such experiments, data in tracking control studies led Craik to conclude the human operator behaves basically as an intermittent correction servo or intermittent correction machine.

Craik's work provides three legacies (Corker, in press). The first is to describe human and machines in collaboration in the same mathematical terms, in the same structural terms, and in the same dynamic terms. The second is that his work provides an analytic capability to define the information that should be displayed to the human operator in the human system as a consequence of the sensory/perceptual and cognitive characteristics in control. The final legacy is a fundamental paradigm shift in which man-machine systems could be conceptualized as a single entity linked/coupled to perform a specific task or set of tasks. A new level of abstraction was introduced and systematized by Craik and subsequent developers of operator control models. In this paradigm, the description of the operator in the man-machine system could be used to guide the machine design. Further, the linked system could be used to explore the parameters of human performance, i.e., by changing the characteristics of the machine the scientist could observe the human's response and infer something about the characteristics of the human operator.

McRuer and Krendall (1957) further refined Craik's (1947) servo formulation into the servo model of human behavior. This model characterized the behavioral actions that accompany human performance with feedback and delayed feedback in rotary systems. This refinement led to a relationship between the effective operation of a control and its operator. The control order and the rate of change in physical characteristics of neuromotor control needs to be within the perceptual, cognitive, and neuromotor constraints of the operator. If it is not, then system instability will result.

This servo model of the human operator subsequently guided the design of aiding systems for the operator in the servo task (Birmingham & Taylor, 1954). The algorithms within these models were built along engineering lines of human performance by indicating that the human operator in tracking systems tasks can operate as a good servo because of their ability to identify consistent forcing functions and consistent response in control. Engineering models were developed to quantify aspects of human performance thus allowing some aspects of the usability of a technology to be predicted from an analysis of a task network. Engineering models have focussed primarily on the individual components making up human behavior.

Cognitive modeling concepts were integrated into the philosophy of engineering models in order to assist in predicting complex human operations. The overall philosophy behind the use of cognitive modeling was to provide engineering-based models of human performance. The engineering-based models of human performance permit a priori predictions of human behavior of a very restricted set of behaviors in response to specific tasks. Human performance modeling has traditionally been used to predict sensory processes (Gawron, Laughery, Jorgensen, & Polito, 1983), aspects of human cognition (Newell, 1990), and human motor responses to system tasks (Fitts & Posner, 1967).

Following the control representation of a human operator's mode of control in a system has been the representation of the "internal models and cognitive function" of the human operator in complex control systems. These systems are a hybrid of continuous control, discrete control, and critical decision-making. These systems are characterized by critical coupling among control elements that have shared responsibility among humans and machines in a shifting and context-sensitive function (Sarter, Woods, & Billings, 1997). Although the scope of the human performance modeling tools has changed over the years, current human performance modeling algorithms are still based on Newell and Simon's (1972) model of complex human behavior.

As noted, human performance modeling tools have been especially useful in studying complex input and output behaviors (Lee, 1998; Laughery & Corker, 1997). The growth in human performance modeling over the more recent term has been to examine human performance in complex systems (including system monitoring) as opposed to the closed-loop view of the human as a mathematical relationship between input and output to a system (Laughery & Corker, 1997). In fact, new human-computer simulation modeling programs have been proposed to study human performance interacting with systems (Laughery & Corker, 1997) and to support prediction of future system state (Lee, 1998). These hybrids of continuous control, discrete control, and critical decision-making models have been undertaken to represent the "internal models and cognitive function" of the human operator in complex control systems. These hybrid systems involve a critical coupling among humans and machines in a shifting and context sensitive function (Sarter, et al. 1997). The nature of a human's interaction with a system often changes the behaviors required for completing the tasks. Often, this change in the interaction of the human with the system is the result of increases in technologies and automation (Endsley, 1997; Laughery & Corker, 1997; Sheridan & Ferrell, 1974).

As the human operator was served by automation that operated at remote sites in semi-autonomous modes, a new set of model descriptors was developed led by Sheridan's work in Supervisory Control (Sheridan & Ferrell, 1974). In this mode, the operator stands back from the direct manual control of the systems and has managerial functions, setting goals, training, observing performance, and intervening when performance is deemed inadequate among other things. The requirement for local autonomy of a function could be thought of in terms of distance/time relationships, bandwidth limits, or efficiencies gained by removing the human from the direct critical path of control. This view of human as supervisor has spawned a considerable body of research and development. Increases in technologies and in automation in order to complete complex tasks may result in an increase in danger for the human operator because of a reliance on these automated systems (Endsley, 1997). Implementation of these technologies on a vast system-wide application without a full evaluation of the costs associated with such a transition would not be prudent. It is for this reason that the human performance modeling tool is considered. Implementation of these technologies on a vast system-wide application without a full evaluation of the costs associated with such a transition would not be prudent. It is for this reason that the human performance modeling tool is considered a valuable resource to supplement experimentation.

Human Performance Modeling Tool Operation

Human performance modeling tools operate in one of two ways. One method is to run a preset number of Monte Carlo simulations, a process in which random variables are manipulated, on a predefined scenario with a specific variable changed at a predefined time in the set of Monte Carlo simulations. Once this variable has been changed, a second series of Monte Carlo simulation runs is performed again. A comparison is then made between the set of output values from the first set of runs with the second set of runs. This is a test that is performed in the validation and verification of the modeling tool. The second method for running through a human performance model is to have an experimental design established and have the human performance modeling tool generate responses given the manipulations outlined in the experimental design. The modeling software selects from a common random number (CRN) table and uses these human performance values in the Monte Carlo runs. These runs are performed a number of times similar to testing a number of subjects and drawing inferences based on the output from the subjects. The data from the CRN matrix that the human performance modeling tool uses in its generation of response values comes from human performance and human cognition research (IPME, 1998). The human performance modeling software tool selects from the CRN table built within each modeling tool and then uses these values in the Monte Carlo simulation run.

There are two main engineering classes of human performance models that accomplish the task of studying human performance with systems. These two classes of models are those that fall under the Reductionist principles, and those that are based on the emergent human behaviors also termed the First Principles models of human performance (Laughery & Corker, 1997).

Reductionist Modeling

Reductionist models use a human-task sequence as the primary organizing structure. In order to accomplish this human-task sequence, Reductionist models utilize a task-network modeling approach. In a task network model, task decomposition of a skilled behavior is performed (Laughery & Corker, 1997). In order to accomplish the task decomposition, a comprehensive task analysis is performed of the tasks involved in the completion of the behavior in response to the system under study (Laughery & Corker, 1997). The individual model of human behavior for each task or task element is linked to the task sequencing structure discovered through the task analysis. Reductionist models, therefore, use the human/system task sequence as the primary organizing structure. This is referred to as a Reductionist model because the larger aspects of human behavior are successively reduced into smaller elements of behavior. The decomposition continues until a level is reached at which point reasonable estimates of human performance for the task elements can be made. Two examples of well known and previously validated task decomposition models include Card, Moran, and Newell's (1983) goals, operators, method and selection rules (GOMS) and the MicroSaint task network model (Laughery & Corker, 1997). For a complete review of the various other task analysis and cognitive task analysis techniques consult John and Kieras (1994), Card et al. (1983), and Kirlik & Bisantz (in press).

Once the modeler has performed an appropriate level of task decomposition the human performance simulation model is subjected to a verification/validation process. This process involves a variety of techniques to check that the model produces reliable and valid data for the task being modeled. Banks (1998) outlines four main categories of validation/verification techniques which include informal, static, dynamic, and formal testing methods (for a complete discussion see Banks, 1998). Following the verification process, the operations of the model can be set to run through the set of tasks programmed into the model. Under the Reductionist framework, the human performance modeling software tool is run in a Monte Carlo simulation process to predict the statistical distributions of measures of overall performance. The early aim of these models was to determine the time and accuracy of human performance through an examination of the shift of the time distributions or completion probabilities of all component tasks to be performed by the human operator.

Advantages and Disadvantages of Reductionist Modeling

Reductionist modeling has been sustained for modeling human performance in complex systems for a number of reasons (Laughery & Corker, 1997). Reductionist models of human performance modeling are advantageous as they may be applied at three broad levels of granularity: the general level, the unit task level, and the micro-task level. Complex systems are represented by networks of component processes each being modeled by statistical distributions of completion times and probabilities of success. The task analysis outlines the behaviors that are engaged in beginning with a task acquisition loop. This loop models the process of task acquisition, identifies the nature of the task, selects a method appropriate to completing the task, executes the method and then returns to the task acquisition method. Next, the task network possesses embedded sub-models of plant hardware and software that allow a closed-loop representation of the human-machine system to be made. This intermediate level is defined by the interface between the primary subtasks identified at the top level. The final level describes how the selected function is actually executed by means of a sequence of cognitive operations and physical actions necessary to accomplish the goals. The task network model has continued to be used because of its relative ease of use and understandability. The task network model can also provide reasonable input to many types of issues. Task network models have been subjected to validation studies with favorable results (Lawless, Laughery, & Perensky, 1995). It is interesting to note however that although the task network has been subjected to many validation studies with favorable results, there are two dimensions upon which the task network should be evaluated, the procedural process as well as the generalizability of the task being modeled (Laughery & Corker, 1997).

The Reductionist family of models does possess some limitations. The model is targeted towards modeling expert users of a system and does not account for the possibility that human error can occur with these expert users (Laughery & Corker, 1997). Reductionist models do not account for either system learning or system recall after a period of disuse. It appears that Reductionist models have focussed on explicit elementary perceptual and motor components while treating the cognitive processes in skilled behavior including mental workload in a less distinguished fashion than is truly representative of human operations. This results in Reductionist human performance models primarily linking the human's activities to the task network model. The Reductionist models do not address systems in which tasks should be performed by the system while the human operator monitors the system. These studies are therefore limited in their application to the use of automated systems. Laughery and Corker (1997) indicate that the Reductionist model addresses only the usability of a task on a system. The model does not address the amount and kind of fatigue that can be experienced by expert users. Individual differences among users are not accounted for in the model. These difficulties with the Reductionist models to study human performance result in their limited application to early design intervention, one of the fundamental tenets of human performance modeling (Laughery & Corker, 1997). For this reason there has been the development of another family of models that account for some of the limitations of the Reductionist approach to studying human performance, namely the First Principles approach to modeling.

First Principles Modeling

The First Principles models of human performance are based on the mechanisms that underlie and cause human behavior (Laughery & Corker, 1997). First Principles models integrate human perceptual and cognitive systems and human motor system representations thus incorporating the high level behaviors that are characteristic of human performance. First Principles models of human performance include filters that affect the tasks that are going to be performed in the system and then act as inputs to the system for subsequent task completion. The First Principles model of human performance provides models of emergent human behavior based on elementary models of human behaviors such as perception, attention, working memory, long-term memory, and decision making (Laughery & Corker, 1997). In the operation of these fundamental models there are some characteristics of the task networking modeling approach.

However, the First Principles modeling approach focuses on micro-models of human performance that feed-forward and feedback to other constituent models in the human system. First Principles models allow for system learning and system recall, a limitation with Reductionist modeling approaches. First Principles models allow for learning and recall by integrating the theoretical and pragmatic models of human behavior into an integrated human performance model (AGARD, 1998). The incorporation of the constituent models into the integrated human performance model allows for the human operator to be treated as a holistic operator. The integration of these models can be seen in Figure 3.

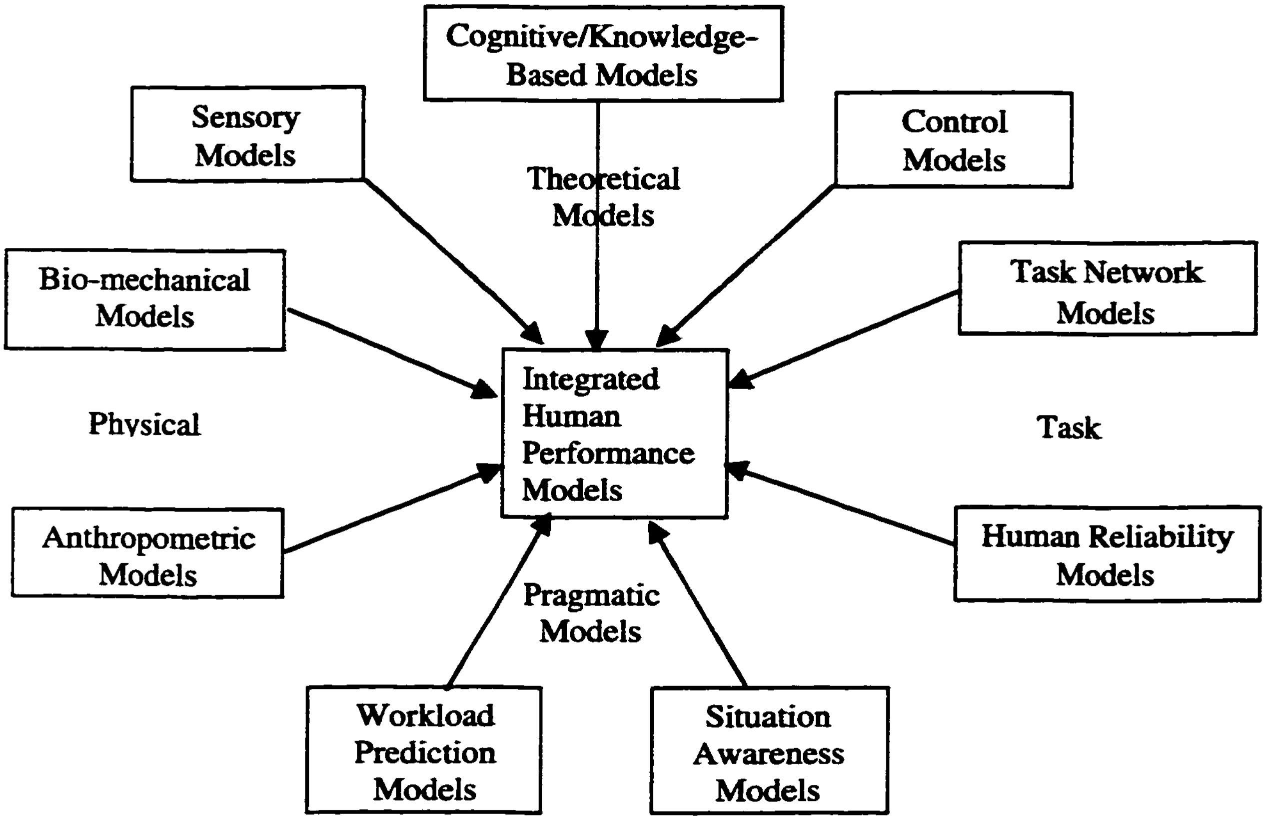


Figure 3. Human Performance Modeling Integration (AGARD, 1998). First Principles models integrate human perceptual and cognitive models and human motor system representations thus incorporating the high level behaviors that are characteristic of human performance.

Advantages and Disadvantages of First Principles Modeling Tools

The First Principles models have built on some of the limitations of the Reductionist models. First Principles models of human behavior are structured around an organizing framework that represents the underlying goals and principles of human performance (Laughery & Corker, 1997). For example, First Principles models account for human learning of a system and its recall after a period of disuse. Furthermore, First Principles models have focussed to a greater extent on cognitive processes in skilled behavior, including mental workload. It is interesting to note however that some of the First Principles models are built with a Reductionist framework in mind while others are more consistent with the emergent behaviors of the operator.

First Principles models and modeling in general have the limitation that the models embedded within the First Principles model software may not be fully inclusive. It is for this reason that there needs to be a comprehensive assessment of the models' abilities to accurately represent the human operator and the actual human performance with the system. The researcher needs to account for these limitations when generating conclusions from the human performance model.

Each of the human performance modeling approaches, Reductionist and First Principles described above is not mutually exclusive for any given task. Most tasks are more than simply the sum of the individual skills that make up the task. Additionally, most tasks involve a combination of human skills with an environmental interaction on the human's abilities. This means that there needs to be more than simply the decomposition of a task into its individual sub-components. Rather there needs to be a model that has the flexibility to break a task into its sub-components combined with a model of the human performance attributes operating in complex automated systems, a combination of First Principles and Reductionist ideologies.

Two human performance modeling tools have been developed that follow the First Principles ideologies and incorporate the Reductionist principle in predicting human performance, namely the Man-machine Integration Design and Analysis System (MIDAS) and the Integrated Performance Modeling Environment (IPME). A discussion of each of MIDAS and IPME follows.

Man-machine Integration Design and Analysis System (MIDAS)

The Man-machine Integration Design and Analysis System (MIDAS) exemplifies a First Principles approach to human performance modeling of an individual (Laughery & Corker, 1997). The basic structure of the core system presented here is based on the work of Tyler, Neukom, Logan, and Shively (1998). This is the most recent version of the MIDAS modeling tool. The current study used a version of MIDAS termed Air MIDAS that possesses a subset of the core version of MIDAS. Air MIDAS will be explained following an explanation of the core system.

The model designer enters the system through the Graphical User Interface (GUI) that provides the main interaction between the designer and the MIDAS system. The user selects among four functions in the system. Generally the sequence requires the user to establish (create and/or edit) a domain model (which includes establishment and selection of the parameters of performance for the human operator model(s) in the simulation). The user can then select the graphical animation or view to support one or more simulations. The user is able to specify in the simulation module the execution and display parameters for a given simulation set, and specify the data to-be-collected and analyzed in the results analysis system as a result of running the simulation. The results analysis system also provides functionality for archival processes for various simulation sessions. The other underlying MIDAS architectural components include a human operator model, memory representation models, attentional control models, activity representation models, task activity models, and decision-making models. These seven models interact to produce human behavior that is based on environmental influences.

The domain model consists of a library of descriptors that support the creation of vehicle characteristics, environment characteristics, crew station/equipment characteristics, the human operator model (HO), mission and activity models, memory representation, attention control, task agenda and decision-making models. The HO model is the underlying model that guides MIDAS' behavior. HO allows for the production of behavior and responses for single and multiple operators in the scenarios. The HO is the key to the MIDAS function as a predictive design aid. The HO is composed of sub-models in an integrated format including an anthropometric model, sensation and perception models, attention (and other resource models), central processing cognitive functions such as decision-making, evaluation and action selection, and finally behavioral models to guide the anthropometric model in the execution of action. The second model that is vital for MIDAS is the goal-related model. This goal-related model makes the MIDAS architecture First Principled because this is where the goals are stored within the operator. This constitutes the model make-up of the human operator's high level behavioral repertoire in the mission simulation.

MIDAS possesses models embedded within its framework that describe the expected human operator's responses in several areas that are required for the safe and reliable operation of advanced aviation systems (Figure 4) (Pisanich & Corker, 1995; Corker & Pisanich, 1995a; Corker, Lozito, & Pisanich, 1994; Corker & Smith, 1993). This object-oriented software structure is composed of objects and software entities that maintain and manipulate values representing human, equipment and environmental states.

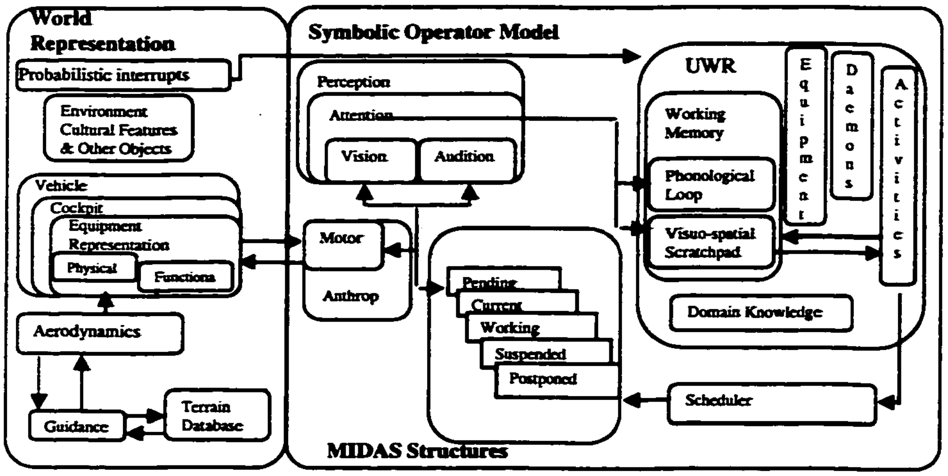


Figure 4. Graphical representation of the Man-machine Integration Design and Analysis System (MIDAS) modules of cognitive human activity.

As seen in Figure 4, MIDAS is made up of interconnected systems that interact with each other. Objects in MIDAS interact with each other by exchanging messages through agent architectures. MIDAS' agent architecture is made up of physical component agents and human operator agents (Corker & Smith, 1993). Physical component agents use commercially available computer-aided design (CAD) databases to graphically represent physical entities in an environment. Physical world agents are the external environmental influences such as terrain and aeronautical equipment. The human operator agents are made up of human performance representations of cognitive, perceptual and motor operations of a task. These models describe within their limits of accuracy the responses that can be expected of the human operator for safe operation of advanced automated technologies. The attention demands are based on the McCracken-Aldrich method for quantifying attention (Laughery & Corker, 1997). Combining demands along the visual, auditory, cognitive and psychomotor (VACP) resources produces measures of attention demands. In addition, MIDAS possesses degradation functions that incorporate the effects of a stressor on skill performance. Physical representations of the human operator are accomplished through the anthropometric tool, Jack™ (Corker & Smith, 1993). This agent's purpose is to represent the human figure in the form of an animated mannequin that moves through various postures. Perception and attention in MIDAS is solely focussed on modeling visual perception. Within this visual field is an attention field to which Jack™ is attending. The Updateable World Representation (UWR) provides a structure whereby each of multiple human agents representing individuals and teams access personalized information about the operational world. The representational models along with the research basis for the models in MIDAS can be found in Table 1.

Table 1

Empirical research for representational Man-machine Integration Design and Analysis (MIDAS) models.

MICRO-MODELS	EMPIRICAL RESEARCH
Visual Processing (field of view)	Arditi & Azueta (1992) Lubin & Bergen (1992)
Visual Perception	Remington, Johnston & Yantis (1992)
Auditory Processing	Card, Moran & Newell (1983)
Central Processing and Memory	Baddeley & Hitch (1974)
Effectors/Output Behavior (35 primitive tasks)	Hamilton, Bierbaum, & Fullford (1990)
Attention - Multiple Resource Theory	Wickens (1992)
Anthropometric Models	Baddler, Phillips & Weber (1993)

When MIDAS is applied to the air environment, it is termed Air MIDAS. The Air MIDAS software is a parallel development effort to the MIDAS software described in the above section. The Air MIDAS software has been designed primarily for computer programmers in an attempt to incorporate new aspects of human performance in the modeling tool using a subset of the core MIDAS model. The Air MIDAS software incorporates augmented human operation related to team performance over the single operator that is contained within MIDAS. Air MIDAS does contain the representational models within its structure as does MIDAS. Figure 5 demonstrates the development process that MIDAS has followed and the relationship of the MIDAS models. It can be seen in Figure 5 that the MIDAS development effort has been broken into two parallel development efforts. One effort is focussing on the creation of MIDAS. This development effort has focussed on the individual operator in the framework of psychological theory. The parallel development effort of Air MIDAS has been incorporating the team aspects of human behavior in the framework of psychological theory. Figure 5 also indicates the degree to which the tool is user friendly. This is indicated by the term Graphic User Interface (GUI). When there was no GUI in the modeling software, the software was primarily designed for programmer's use while when the GUI is present, it is being designed for a programmer that may not be as versed in the LISP programming language.

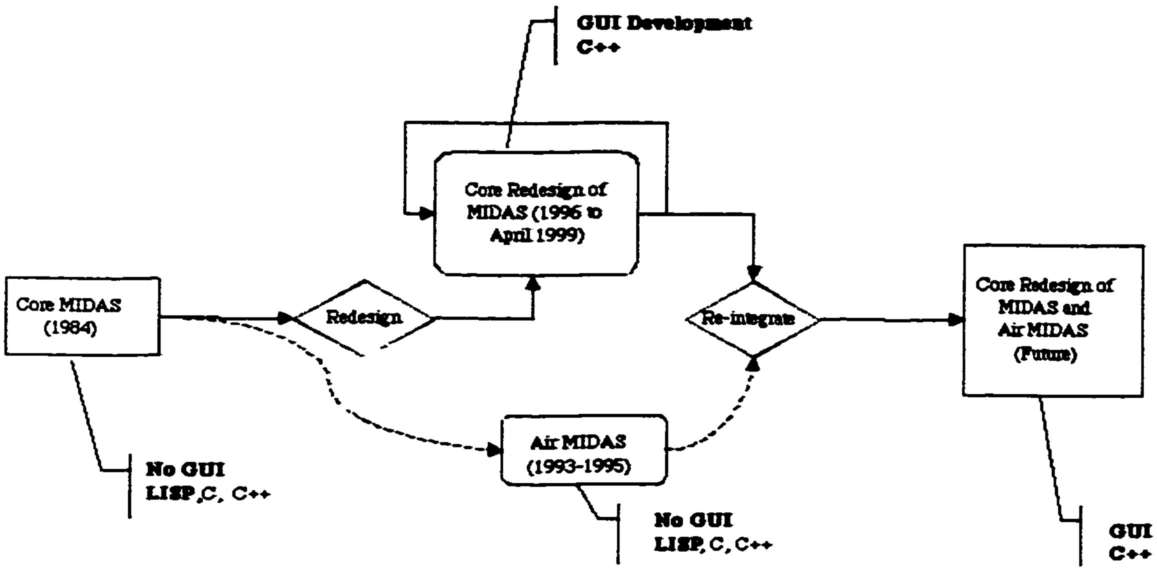


Figure 5. MIDAS/Air MIDAS Parallel Development Process. MIDAS development effort has been broken into two parallel development efforts. One effort is focussing on the creation of MIDAS. This development effort has focussed on the individual operator in the framework of psychological theory. The parallel development effort of Air MIDAS has been incorporating the team aspects of human behavior in the framework of psychological theory.

Another system labeled the Integrated Performance Modeling Environment (IPME) also enables a First Principles approach to human performance modeling from a system perspective. The IPME contains the functionality of the Reductionist approach for those aspects of the model that are insufficiently defined within the micro models of the IPME. An explanation of the IPME follows.

The Integrated Performance Modeling Environment (IPME): A Hybrid Approach

The IPME is a commercially available software product that incorporates many aspects from the Reductionist approach with the First Principles approach to human performance modeling. The IPME was developed in 1995 for the UK Ministry of Defense and Corporate Research Programme (CRP) to quantify human performance to system effectiveness (AGARD, 1998). IPME has been designed around a Reductionist framework while representing similar psychological processes to MIDAS. The structure of the IPME is centered around the task decomposition as opposed to the psychological functionality of MIDAS. IPME combines these psychological processes with physical task completion times and multiple operator task performance times. IPME accomplishes this through micro-models, task scheduling, sensation and perception, cognition and motor outputs. The IPME also incorporates design parameters of the workspace in which the processes must be completed as well as describing the processes used by a human operator to perform a task (IPME, 1998). In addition to these physical aspects of a task, the IPME combines various aspects of human performance in task accomplishment. These human performance characteristics include the Human Factors Task Database (HFTD), Micro Saint Human Operator Models (MS HOS), physical environment, workspace environment, operator characteristics, and the simulation and performance shaping factors (PSF). The interactive nature of this model can be seen in Figure 6.

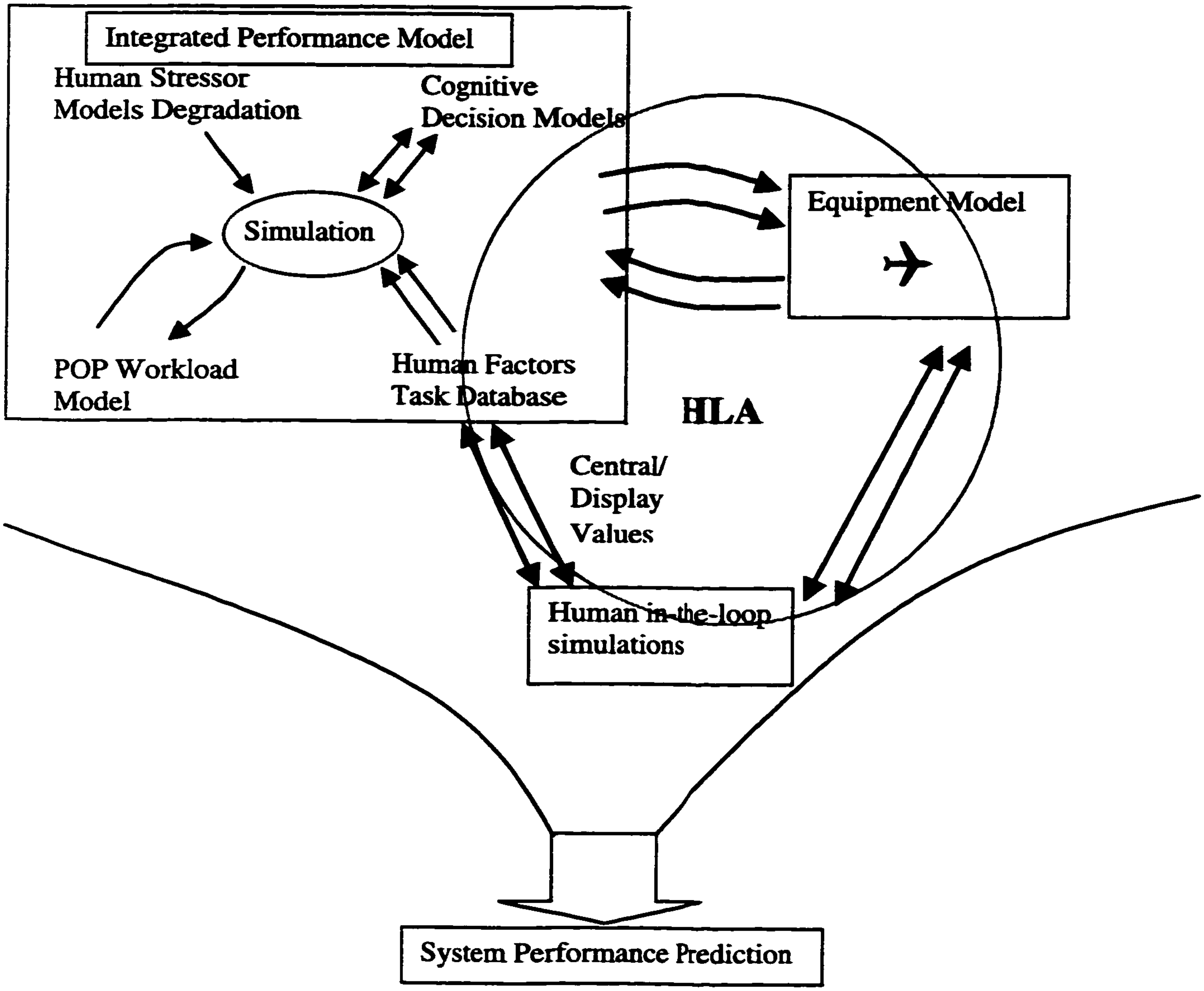


Figure 6. Human Performance Modeling in the Integrated Performance Modeling Environment (IPME). IPME combines psychological processes with physical task completion times and multiple operator task performance times. IPME accomplishes this through micro models, task scheduling, sensation and perception, cognition and motor outputs. The IPME also incorporates design parameters of the workspace in which the processes must be completed as well as describing the processes used by a human operator to perform a task (IPME, 1998). In addition to these physical aspects of a task, the IPME combines various aspects of human performance in task accomplishment. All of these structures are combined through the higher level architecture (HLA).

Figure 6 demonstrates that this model not only addresses the physical design parameters of the workspace but also includes the design characteristics in the calculation of system response times and accuracy of the processes involved in the activity under study. The HFTD contains information regarding human-related aspects of operator performance collected during a task analysis and entered into a Configuration Controlled database (IPME, 1998). The HFTD allows importing HFTD Data to populate a model with selective information contained within the database. MS HOS on the other hand accesses a library of information based on empirical research called micro models to assist in calculating various types of perceptual, cognitive, and psychomotor human performance abilities and times related to task performance. Table 2 outlines the values used in IPME and the body of research upon which the values were chosen. These micro models are based on existing literature of perceptual processing times (IPME, 1998). Many of these MS HOS micro model processing times are similar to those that MIDAS' anthropometric tool Jack™ utilizes (IPME, 1998).

Table 2

Empirical Research for Representational Integrated Performance Modeling Environment (IPME) Micro Models.

MICRO-MODELS	HUMAN FUNCTION	EMPIRICAL RESEARCH
Perceptual	Eye and head movement times and eye fixation time	Sanders & Houtmans (1984)
	Search	Sanders & Houtmans (1984)
	Reading rates	Card, Moran, & Newell (1983)
	Listening rates	Miller & Licklider (1950)
	Visual acuity	Johnston (1965)
Motor	Hand movement time	Welford (1968)
	Push button/rotary dial times	Harris, Iavecchia, & Bittner (1988)
	Walking rate	Harris, Iavecchia, & Bittner (1988)
	Single finger keying rate	Card, Moran, & Newell (1983)
	Cursor movement times	Card, Moran, & Newell (1983)
		Harris, Iavecchia, & Bittner (1988)
	Speech production times	McCormick (1970)
Cognitive	Perceptual process, decision process and motor process	Card, Moran, & Newell (1983)
	Choice reaction time	Card, Moran, & Newell (1983)

IPME contains multiple modes that can be selected to measure workload (IPME, 1998). The first mode is one that permits the flexibility of assigning the visual, auditory, cognitive, and psychomotor (VACP) values into the model development. These VACP values allow similar loadings used to measure workload and attention that are used in MIDAS for determining the resources that are used when engaged in specific tasks. These scales are measured along the McCracken and Aldrich scale associated with task demands (Laughery & Corker, 1997). This scale is measured along a seven-point scale and is based upon extensive research on attentional demands.

IPME can also be used in the Prediction of Operator Performance (POP) mode that allows for the IPME to schedule a delay in task completion given tasks that are currently being performed. IPME possesses an internal scheduler for the timing and organization of the respective tasks. The workload scales used in this POP mode are based on a 100-point scale of workload values along the dimensions of input, central, and output demands on resources associated with a task. The input demands are demands imposed by the acquisition of information from external sources such as visual or auditory signals. The central demands are those demands imposed by mental calculations such as memorization, calculation, and decision making. The output demands are those that are imposed by the responses of the operator; either being manual or vocal. Incorporated with the three resource demands are times that the resource will be occupied while completing the task. These timing values determine whether the internal scheduler in IPME schedules a task delay and the length of this delay.

IPME further has the flexibility of being set to run using the Information Processing/Perceptual Control Theory Model (IP/PCT). The IP model represents a timeline of a modeled activity and does not provide an actual measure of workload. Workload and performance needs to be inferred from the coupling of IPME and the model of the human information processor. The information-processing model includes a representation of the operator's allocation of attention and human memory together with a framework for tracking load operator's information processing system. IP/PCT adjusts operator performance based on task level stressors that degrade human performance on the primary task. These can be set at the global level or the task level. The IP's include perceptual decision and motor processes, on/off response, physical match, name match, class match, and choice reaction times through task interference. For concurrent task performance, the IP model recognizes both structural and resource limited interference. Structural interference is used to describe performance effects due to limitations in operator structural performance. Examples of these include the inability to focus on two or more different images, problems associated with operating different controls with the same hand/limb or the inability to speak two messages simultaneously. Resource-limited interference develops as a result of a competition between common processing structures. Within this cognitive domain, the degree of interference is graded. When the demand load exceeds the operator load, the IP model uses a scheduler to determine the order of the tasks. The scheduler uses queues to store the schedule of different tasks. When conflicts exist between queues, tasks can be interrupted, deferred, shed, or removed at this point. The event type, data elements, and values determined by the IPME predictive workload micro-model is indicated in Table 3.

Table 3

Event Type, Data Elements, and Values Determined by the Integrated Performance Modeling Environment (IPME) Program.

Event Type	Data Element	Values
IP Interrupt	Reason for interruption	Priority, interference, random
IP Delay	Reason for delay	Priority, interference, random, uninterruptable task, task>tp_{crit}
	Delay time	Total time – Processed time
IP Shed	Reason for shedding	Number of attempts, priority, predecessor task
	Consequence of shedding	Task halted, following tasks continued, different task followed (task #)
Task Failed	Consequence of failure	No effect, time/failure of another task adjusted, different task follows, task repeats, model terminates.
Task Complete	Total time	N
	Processed time	N

The interactive nature of this modeling tool enables individual micro-models to be created and used in combination with the human performance subsystems through a higher level architecture (HLA) (see Figure 3) (Laughery, 1998). This HLA provides feedback to other constituent models within IPME. The incorporation of the HFTD, the MS HOS, the environment variables, the operator characteristics, and the performance modification factors result in this HLA being somewhat of a hybrid system as it utilizes aspects that are Reductionist and aspects that are First Principled. The IPME models both operators and systems dynamically. These models are vital to study the increasing complexity of the aeronautic systems that is certain to accompany a transition to free flight rules of separation. Although it is possible to use the different micro models of workload, the current study chose to use the VACP workload micro model in its evaluation.

There are three workload models contained within IPME for workload measurement. The first model permits the flexibility of assigning VACP values into the model. IPME can be set to operate using the POP model of workload where the model keeps track of the values that are contained within the model and schedules a delay in task completion time given the demands associated with the first task. The final workload measure is through the IP/PCT model.

The IPME also contains characteristics of a good unified theory. It is made up of a number of solid theoretical human performance timing algorithms within the performance model MS HOS. The integrated nature of IPME allows for easy representation of the operating environment and the interaction of this environment with the human operator. IPME incorporates team operation in a system into the modeling environment that allows accurate representation of team interaction. IPME incorporates equipment models into the development of the scenario as well. IPME has the limitation that the models embedded within it may not be fully inclusive. The IPME model is only as good as the values that are programmed within it. For this reason, there needs to be a comprehensive assessment of the models' abilities to accurately represent the human operator and the actual human performance with the system. This is because the nature of the hybrid model such as IPME is targeted more towards the task nature of human performance rather than dealing with the goal behavior of the operator. The task decomposition method may not model the emergent behaviors that are elicited from the human. Hybrid modeling tools such as IPME have attempted to implement some of the benefits of the First Principles modeling tools. In so doing however, certain other beneficial aspects of the human performance model have been omitted. IPME has been designed to degrade task performance from the PSF and not provide the full emergent behaviors, such as attention measures, as a function of the task demands. For this reason, the IPME design may omit some aspects of the goal-directed nature of human behavior.

Similarities and Differences Between the First Principles Models

Air MIDAS and IPME have been designed with the same philosophy in mind, namely that of the influence of emergent human behaviors on task accomplishment combined with environmental influences. Although the current outline thus far has mainly focussed on similarities of the philosophical development of the models, there are differences in the task-scheduling component of the model and in the attention models used. The First Principles models have been designed with the goal of attributing the performance of individuals to more than simply the mathematical relationship between task and task accomplishment as is the case in Reductionist modeling. First Principles have been designed with the ideology of being unified. This unified nature of the model permits a sufficiently accurate evaluation and examination of the interaction between the human performance limitations and the tasks that are required of the human operator. First Principles models are now being augmented to include additional components of human perception and decision making as it relates to team operations. It is primarily in the semantic organization of the output that models are termed emergent. Those emergent-behavior models like MIDAS that are closer to a "pure" emergent-behavior model are able to output the data in packets that are associated with the human performance structure as opposed to simply the time associated with the performance of a task. Emergent-behavior models such as IPME that are not a close to the "pure" emergent style of model are unable to provide output or predictions based on this emergent structure of human performance.

MIDAS is a First Principles model that has been under development for over 10 years. Air MIDAS, the parallel development effort to MIDAS that began in 1995, has been developed to serve as a cognitive predictor model applied to the air environment. As a result, Air MIDAS may not incorporate all of the models related to task performance that MIDAS or IPME contain.

IPME is a model that has been developed to serve as a predictor of task performance. IPME contains multiple workload models, some which are predictive. IPME has an added attention decrement model, Performance-Shaping Factors (PSF) and the POP models related to team performance. The additional models built within IPME were designed primarily for team decision making and auditory attention decrements.

This is one reason that IPME has previously been determined sufficiently valid for team operations. IPME also contains a model for measuring the situation awareness of an operator. Given the interactive nature of the First Principles models, there can be little doubt that this SA measure is likely to be incorporated in other First Principles models.

This initial attempt at modeling human performance in transitioning between current day and future free flight operations in an experimental manner will highlight potential impact areas for human performance as identified by a modeling tool. Specific scenarios have been identified to challenge human operators' performance. These scenarios are the generating scenarios for the evaluation of free flight operations on human performance. The identified scenarios will include modeling human performance in conflict situations when dealing in different traffic density conditions, different cross-sector conditions, and different emergency conditions.

Multiple methods exist for modeling human performance. Two methods have been selected to measure the impact of the rule set change on human performance. The two methods include one that is based on the framework of the task network and one that is based on the framework of psychological principles of human performance combined with the Reductionist principles of completing the goal behavior.

Human performance modeling tools are designed to measure operational timing and distance characteristics, and four operator workload channels representing an operator's visual, auditory, cognitive and psychomotor (VACP) demands. The system measures include initializing versus terminating the conflict event, level of alert, time of the alert, decision times, handoff times, handoff completion times, emergency broadcast times, and times to emergency broadcast completion. The operator efficiency measures include the workload trace associated with each of the highlighted areas of concern. Workload trace is measured by VACP demands associated with the task network.

It is useful to think of the modeling process in three phases. These phases include the task decomposition phase, the model development phase and the experimental manipulation phase. The task decomposition phase requires a literature review and task analysis. This task analysis can be performed either through a rigid structured task analysis or a less formal method using Subject Matter Experts (SME) to determine the activities that are performed in accomplishing the goal behavior. The second phase is the model development phase where the model is created in both Air MIDAS and IPME given the structure established by the first phase. The third phase is the experimental stage where model runs can be performed given manipulations of interest to the researcher. These phases are outlined in Figure 7.

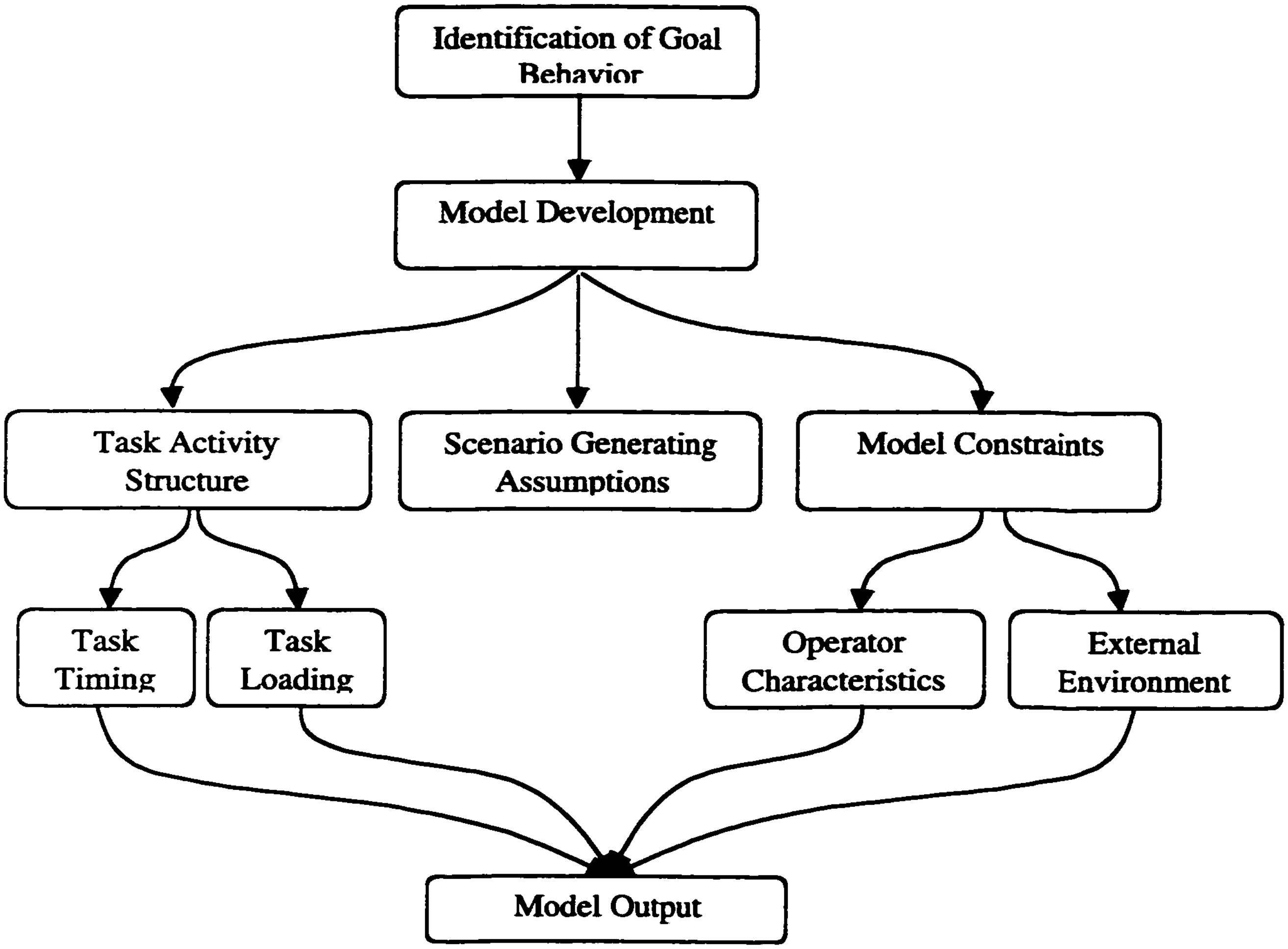


Figure 7. Steps in Completing this Modeling Effort.

The first step in any modeling project is to identify the behaviors that warrant further evaluation. Once this goal behavior has been identified, the series of individual behaviors that are performed to complete the goal behavior is required. This is indeed what was done for the current evaluation. The goal-directed behavior was identified as a response from both the ATC and the air systems to a potential conflict situation under each of two rules sets, current day rules of operation and free flight rules of operations. The current day operations, representative of today's normal air operations, are outlined in Appendix 2. The future free flight operations, based on an interpretation of the free flight rules (Wickens, et al., 1998), are outlined in Appendix 3.

The task analyses of en route operations from both air traffic control (Rodgers & Dreschler, 1993; Hamilton, Bierbaum, & McAnulty, 1994) and flight crew perspective (Hamilton et al., 1994) were established and input into the task model that is operationally required by both Air MIDAS and IPME. This task decomposition outlines the tasks that are engaged in for generating the experimental scenarios. All activities in the current evaluation will occur during a conflict situation. Three main groups of activities are of interest in the current evaluation. The activities that are performed by the operators are thought to be influenced by the level of traffic in the airspace (Lozito et al., 1997); therefore the activities performed during low traffic and high traffic levels will be modeled. The modeled activities will also include those that are performed during a handoff condition, and those that are performed during an emergency condition (RTCA, 1995).

A number of different methods were used to obtain the tasks and the data necessary for the creation of the task network within the model. A literature review to identify the aspects of behavior that needed further study was performed. It was found that the transition to free flight was identified as an issue that required the benefits afforded by human performance modeling. The second method was a task analysis of commercial airline pilots that targeted obtaining information about the process of aviating in the en route environment and the rules that are followed by the flight deck when flying with this rule set and dealing with an upcoming conflict situation. These interviews were then validated with videotape observations to gain an understanding of the actual human-in-the-loop simulation performance during full mission simulations of current day operations and free flight activities. A parallel task analysis that targeted the tasks that are followed by the ground was completed with experienced air traffic controllers and consultation with subject matter experts. This initial cognitive and physical task analysis was completed for each of the candidate encounter scenarios for each of the ground and the air-based systems occurring in each of the locus of controls. The results of the videotape analysis were verified with empirical research publications of human performance on free flight operations (Cashion et al., in press; Lozito et al., 1997). These task analyses were validated with published cognitive task analyses of en route air traffic controllers and flight deck tasks from Rodgers and Dreschler (1993) and Hamilton et al., (1994). Once there was a determination of the operators' tasks, subject matter experts were used to determine the order of the tasks. These subject matter experts included commercial airline pilots and air traffic controllers.

In order to gain an understanding of the tasks that are performed in each of these conditions, it is useful to break the tasks down into levels of organization. The two organizational levels include high level and low level task decomposition.

High Level Task Characteristics

There are a number of tasks that are engaged in by the ATC in successfully performing the transition of the aviation system to free flight. Several tasks are the same in current day and in free flight operations. Specifically, ATC monitors the visual information, monitors the auditory information, performs cognitive flight organizations such as planning and scheduling, communicates with the aircraft, and communicates with other ATC. The primary difference between the current day and the future free flight operations involves the level of authority. In the current day operations, the ATC has the primary responsibility of controlling the airspace sector while in free flight operations, the flight crew has the responsibility of controlling their own separation.

A task analysis using flight deck data on the transition to free flight was performed to evaluate the common tasks engaged in by the flight crew (Cashion et al., in press; Lozito et al., 1997). Similar to the ATC, the flight deck also possesses similar responsibilities operating under current day rules and free flight rules. Specifically, the flight crew monitor visual information, monitor auditory information, perform cognitive flight organizations regarding their own aircraft such as adjusting heading, altitude and speed, communicate with the ground, and communicate with other aircraft (Table 4).

Table 4

Parallel Tasks from Ground and Air Perspectives. **The graphic represents the high level tasks that are performed by both the ground and the flight crew.**

High Level Tasks	
Air Traffic Control	Flight Crew
Monitor Visual	Monitor Visual
Monitor Auditory	Monitor Auditory
	Monitor Flight Parameters
Perform Flight Organization • Planning • Scheduling • Clearance	Adjust Flight Parameters • Heading • Speed • Altitude
Communicate with Aircraft	Communicate with Ground
Communicate with Ground	Communicate with Aircraft

The primary difference between the current day and the future free flight operations involves the level of authority. The flight crew will be engaging in increased traffic monitoring and calculating vectors to ensure adequate separation between the aircraft.

Low Level Task Characteristics

Current Day Rules of Operation (LOC1)

As previously indicated, air traffic controllers are responsible for guiding the safe and efficient routing of air traffic (Wickens et al., 1998). An evaluation of existing research (Cashion et al., in press; Lozito et al., 1997) and previous task analyses (Rodgers & Dreschler, 1993) was done on the ATC and the flight crew to determine the required tasks that are performed when dealing with an airspace conflict during current day operations. The cognitive requirements include planning strategies to resolve conflicts, predicting long-term events, comparing criteria and predicting short-term events, transmitting information, remembering, and identifying relevant items of information. The type of processing (visual, cognitive, auditory and psychomotor) required of these tasks was also determined (Corker, Pisanich, & Bunzo, 1997). The pattern of tasks on the ground during a conflict condition involves an automated alert trigger followed by the operator's receipt of the alert, recognition of the alert, memory trigger, communication of the alert, decision, communication of the decision, and action of the controller (Table 5).

Table 5

Low Level Actions of ATC and Flight Crew.

Low Level Tasks Under ATC control	
Air Traffic Control	**Flight Crew**
Monitor Visual	Monitor Visual
Monitor Auditory	Monitor Auditory
	Monitor Flight Parameters
ALERT to ground	
ATC Receipt of Alert	
ATC Recognition of Alert	
Memory Trigger	
Communication of Alert	
Decision	
Communication of decision to air	Communicate with Ground
Action	Adjust Flight Parameters • Heading • Speed • Altitude
Note	Monitor Visual
Monitor Visual	Monitor Auditory
Monitor Auditory	

Low Level Tasks Under Flight Crew Control	
Monitor Visual	Monitor Visual
Monitor Auditory	Monitor Auditory
	Monitor Flight Parameters
ALERT to ground	
ATC Receipt of Alert	
ATC Recognition of Alert	
Memory Trigger	
Communication of Alert internally	
Decision and heightened monitoring	
	ALERT to air
	Communicate with Aircraft
	Adjust Flight Parameters • Heading • Speed • Altitude
	Monitor Visual
	Monitor Auditory
Note resolution	Communicate with Ground

Flight deck behaviors during a conflict condition operating under ATC control include monitoring equipment, routing and active communication. The flight crew does not deal with extensive route planning concerns when engaged in an en route flight environment under air traffic control conditions because their routing has largely been determined and controlled by ATC (Rodgers & Dreschler, 1993; Wickens et al., 1998). ATC provides the flight crew with changes to heading, speed, and altitude and the pilots' role is to carry out the commands requested by the ATC.

Free Flight Rules of Operation (LOC2)

The tasks engaged in by the two crews are surprisingly similar between the two LOC. The differences between the two rules sets lie primarily in the level of authority and responsibility given to the operators in each system. A task analysis from full mission simulation studies (Lozito et al., 1997) examining free flight rules of flight and interpretations of the free flight RTCA rules was done on the ATC to see the tasks required to deal effectively with a conflict (Rodgers & Dreschler, 1993; U.S. Department of Transportation, 1998). The ATC tasks when operating under free flight rules when dealing with a conflict situation include monitoring the actions of the aircraft under the ATC control, and preparing to intervene in the event that action is not taken in time to avoid a potential airspace conflict. When the flight crew are involved in a conflict under free flight rules however, there is the increased likelihood that the tasks required of the flight crew and the associated workload will increase. Part-task simulation research based on Cashion et al. (in press) will be used as the basis for inputting the various components into the models' development of the tasks engaged in by both the ATC and the flight crew while under ATC rules as opposed to free flight rules.

Simulated Controllers

Current Day Rules of Operation (LOC 1)

Simulated controllers will hand off the aircraft in accordance with letters of agreement that exist to hasten the handoff procedure for the airspace under travel. The letters of agreement are informal agreements between ATC and the destination airport which permit the ATC to handoff an aircraft at a constant time prior to the sector transition zone. The letter of agreement time distances for the generic en route airspace sector allow a handoff to occur 3 nautical miles on either side of the critical sector boundary to expedite the handoff procedure. The sector transition zone critical boundary where the aircraft will be handed off is a six-minute (48 nautical miles) window surrounding the sector boundary. Simulated controllers will be provided with additional predictive displays of traffic information (RTCA, 1995). The predictive information will be provided sixteen minutes (128 nautical miles) from the point of closest approach (PCA), this is the point at which the aircraft violate the separation standards between aircraft. This PCA is dependent on the angle of approach between aircraft when measured in terms of time as it is in the current study. All communication in the handoff condition from the ground to the air will take place verbally. All handoff conditions will be manual handoffs where the simulated controllers will be responsible for using a trackball to select a flashing data block and input some typing commands on accepting/rejecting the aircraft. All simulated aircraft will be accepted in the current evaluation. The simulated controller hand off simulated aircraft as a function of distance to boundary and sector complexity associated with the airspace as seen in Figure 8.

Simulated ATC handing off conflicting aircraft must resolve the conflict before handing the aircraft off to the receiving sector.

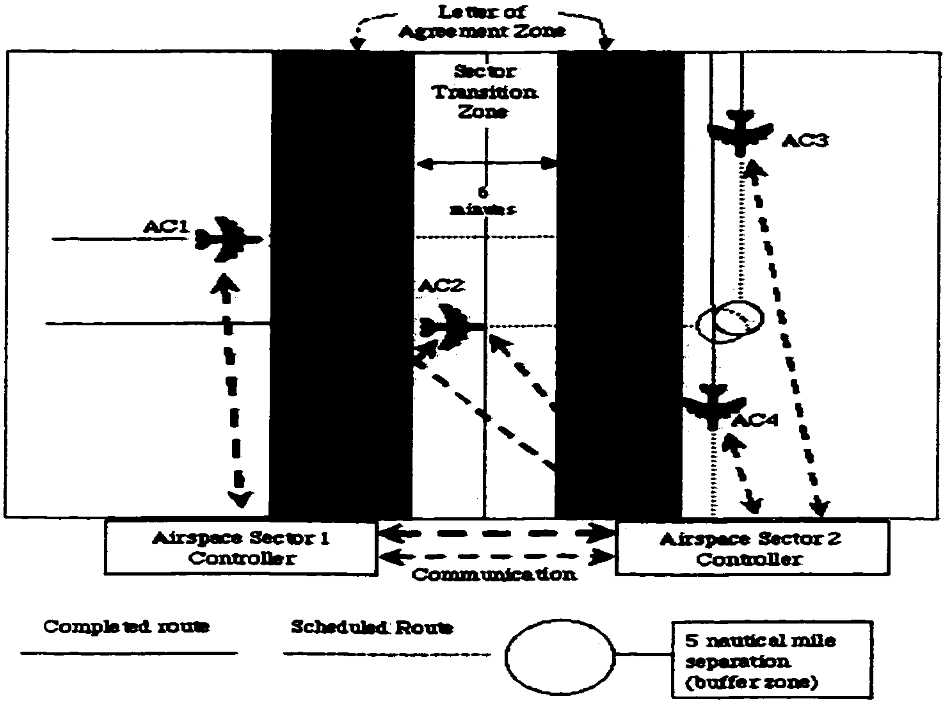


Figure 8. Pictorial Representation of the Current Study. Aircraft (AC) 2 is currently under control of Air Traffic Control Sector 1 (ATC1). AC 1 is at the beginning of the ATC 2 control due to the letter of agreement. AC 1 is at the entrance of the letter of agreement handoff zone. AC 1 can be handed off with the current trajectory as there will not be a conflict situation occurring in the new airspace sector. AC 2 by contrast is on an airspace collision course with AC 3. This will occur in sector 2. ATC1 needs to take action to avoid this conflict situation prior to finalizing the handoff.

In Figure 8, AC 2 is currently under control of ATC 1. AC 1 is at the beginning of the ATC 2 control due to the letter of agreement. AC 1 is at the entrance of the letter of agreement handoff zone where the handoff can begin. AC 1 can be handed off with the current trajectory as there will not be a conflict situation occurring in the new airspace sector. AC 2 by contrast is on an airspace collision course with AC 3. This will occur in sector 2. ATC 1 needs to take action to avoid this conflict situation prior to finalizing the handoff.

Free Flight Rules of Operation (LOC 2)

Simulated controllers will hand off the aircraft along the critical sector boundary of a six-minute (48 nautical miles) window surrounding the sector boundary. This is the value that is currently used in current day operations. The handoff condition will replicate expected use of automated handoff procedures under the free flight rules of operation (LOC 2). Although not examined in the current evaluation, in the free flight condition, ATC has the authority to cancel free flight if airspace conflicts are deemed unavoidable by the ATC. Conflicts will become apparent to the simulated ATC at the same distance to conflict as for the flight deck, 75 nautical miles. Conflicts that become apparent to the sending (controlling) simulated ATC will need to be dealt with before the aircraft is handed off to the receiving sector if the conflict is to occur in the sending (controlling) simulated ATC's sector. If the controlling simulated ATC perceives a conflict situation that is to occur in the receiving simulated ATC's sector then the sending simulated ATC does not need to resolve the conflict; the receiving simulated controller needs to resolve the conflict.

Simulated Flight Deck

Current Day Rules of Operation (LOC 1)

The simulated flight crew operating under current day operations has little active control over their flight plan. The simulated flight crew make changes to the flight plan only when the simulated ATC contacts the simulated flight crew and request the simulated flight crew to make changes to their flight plan. Simulated flight crew must contact and receive positive verification from simulated ATC prior to making any changes in flight plan. The simulated crew will act in accordance with current day operations.

Free Flight Rules of Operation (LOC 2)

The simulated flight crew under free flight operations will be using Visual Flight Rules (VFR) in the en route environment (for a complete discussion of VFR, see Illman, 1993). The rules to deal with a conflict situation will be based on the minimum FAA guidelines: to maintain the aircraft in sight; yield to the aircraft on the right; turn to the right to avoid a head-on conflict (U.S. Department of Transportation, 1998; Wickens et al., 1998). The simulated flight deck possesses displays and automated decision-aiding mechanisms for traffic detection and conflict resolution. This system will give aural alerts along with graphical predictive information regarding the location of the conflict. This predictive information will be provided at approximately 3 minutes (24 nautical miles) from point of closest approach. All conflict resolutions in both LOC will be made verbally. When a conflict situation becomes apparent, the simulated flight crew will deal with the conflict. Their actions will be monitored by the simulated ATC. No letters of agreement will be used in this LOC.

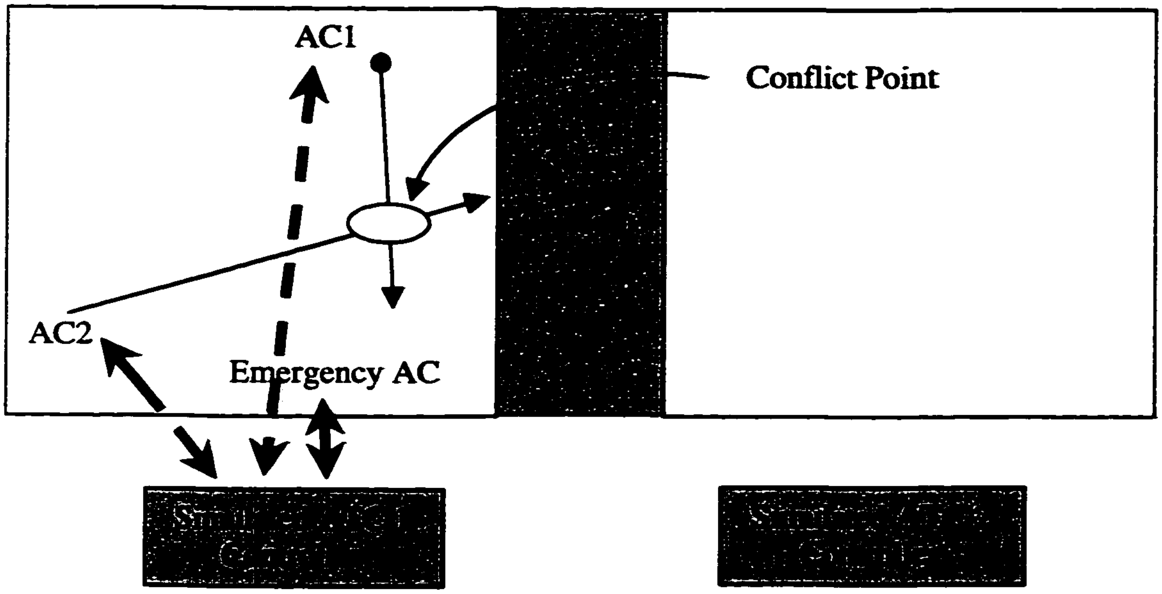
Following the completion of an appropriate task analysis on the goal-directed behavior of interest to the researcher, the researcher needs to identify through use of subject matter experts and existing literature the performance loading and the performance timing associated with the identified tasks.

Scenario Generation

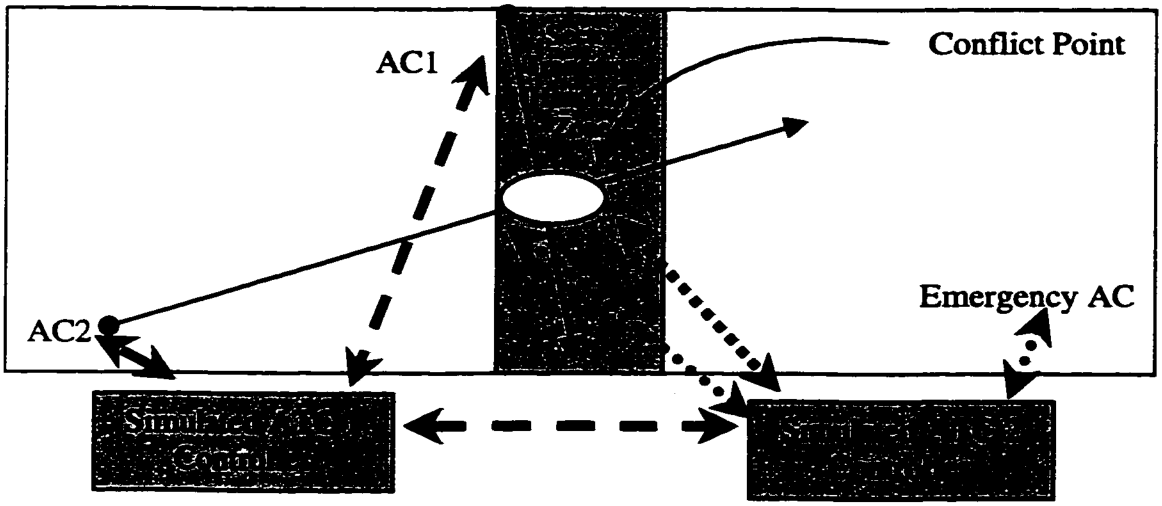
The human performance model operates on a specific set of rules that is played against the scenario that then generates a goal driven behavior. Both scenarios will occur in an en route flight condition of twenty minutes duration traveling through a generic airspace at 35 000 feet (flight level 350). In all scenarios, the ownship aircraft will be subject to an airspace conflict with an intruder aircraft approaching from the East going towards the West. The conflict situation will occur at 12 minutes into the scenario. Conflict conditions between the same two aircraft can only occur once per scenario. The conflict situation becomes apparent to ground control at a distance of 9.375 minutes (75 nautical miles) to PCA.

The virtual aircraft will make vector changes whenever the need arises. Need is operationally defined as impending conflict situation or environmental disturbance (weather or air turbulence). The environmental disturbance or emergency call will be input into the scenario as an event that will require a specified amount of workload which will require a pre-specified amount of resolution time. Simulated flight crew will need to instruct the ground following their resolution decision. All instructions and communications in each scenario will be through current day voice communication as opposed to any form of data link technology. The conflict resolution involving the two sectors is to be handled through verbal ATC to ATC communication. ATC operators are assumed to not be located in close proximity to each other but they will be able to use verbal communication to resolve the loss of separation situation.

Figure 9 demonstrates pictorially the representation of the generating scenario causing the interaction between the aircraft. Appendix 2 and 3 indicates the latitude and longitude values used in the creation of each scenario, the within sector and the multi sector scenario.



Within Sector Conflict Condition: The conflict occurs in sector 1. No handoff is required of the aircraft (AC) between airspace sectors. The Air Traffic Controller (ATC) in sector 1 will not require any communication with the sector 2 ATC. This represents the within sector condition.



Multi Sector Conflict Condition: Conflict is to occur in sector 2. This means that a handoff will have to occur between the two sectors (i.e. AC 1 is handed off from ATC sector 1 to ATC sector 2). ATC sector 1 must deal with the conflict situation before handing off the aircraft to the new sector. The ATC handing off will need to deal with the conflict prior to handing it off. This represents the between sector condition.

Figure 9. Pictorial Representation of the Within and Multi-Sector Conditions under Study.

Along with this procedural analysis associated with the transition to free flight, the methodological comparison between the output of the dependent measures associated with the timing, distance and operator workload of two human performance modeling tools will be performed. It is for this reason that a description of the modeling software follows.

Simulation Software

An evaluation comparing Air MIDAS and IPME human performance modeling strategies was performed. Human performance involves the complex interaction among the physical, perceptual, and cognitive elements of a task. Two examples of First Principles human performance modeling techniques, Air MIDAS and IPME, generated scenarios on a Silicon Graphics Indigo II that realistically represent the human performer operating in a complex multiple-controller, multiple-aircraft environment.

Air MIDAS is a previously validated, psychological-cognitive predictor modeling tool that has been used to successfully predict operator performance in the complex operating environment associated with aviating. For this reason, Air MIDAS is being used to collect data on the timing, distance, and workload measures of human performance operating both in the current day rules of operation and in future free flight operations. Air MIDAS possesses a relatively complex programming environment in which the model construction needs to be rigidly produced to include latitude and longitude values of a real airspace environment.

IPME is a previously validated, task network predictor modeling tool. This has been successfully used for examining individual and group behaviors. IPME was set to collect data on the same dependent variables as Air MIDAS. These dependent variables include the timing, distance, and workload measures of human performance associated with the prediction output from the human performance model. IPME was set to operate using the same VACP measures as Air MIDAS on the same task structure where possible. IPME does not position the aircraft or specify its position in the same fashion as Air MIDAS. IPME does not require the exact programming of the airspace environment; rather IPME can generate the scenario consistent with an X, Y coordinate system.

Task Timing and Workload Characteristics

The loading values that are used by the modeling software tool are the values associated with four demand channels or modalities. These four modalities include the visual, auditory, cognitive and psychomotor modalities (VACP). The data that were used in the model as the loading values of the tasks that were determined from the task analyses were input from the work of McCracken and Aldrich (1984) (See Appendix 6). The McCracken and Aldrich (1984) scale is a standardized seven-point behavioral scale that associates the VACP demands with a number of common aviation–related tasks.

Air MIDAS realistically represents the cognitive aspects of team human operator behavior operating in the air environment (Corker & Pisanich, 1995b). Most tasks represented in Air MIDAS require VACP demands to be incorporated for tasks to be completed. Some tasks however do not require the VACP loading values. These tasks are those tasks that are defined by one aspect of the modality. For instance, if all the demand of a task is represented as a cognitive demand, Air MIDAS assigns a cognitive loading to this task representation. The Air MIDAS program uses these loading values to identify and schedule sequential or concurrent task performance (Pisanich, Corker, &

Bunzo, 1997). The interrupt levels, based on Corker and Pisanich's (1995) detailed list of interruptions, include typical flight deck interruptions such as changing focus onto a display, understanding the information presented and deciding on an action, along with the frequency, duration, and importance of the interruption ('interrupt' level). Consistent with Corker, Pisanich, and Bunzo (1997), only those 'interrupts' that are likely to occur in free flight in an instrumented aircraft were chosen as the interrupt levels to model. These interrupt activities included whether the activity could or could not be interrupted once the activity had begun. In addition to the physical nature of the task completion, human performance requires some form of information processing. The information processing component of the Air MIDAS program includes values based on Corker and Pisanich's (1995) findings of the operator performance based on task level stressors in dealing with a potential conflict situation in Air MIDAS.

The nature of the operations as well as the respective timing values of two forms of activity for dealing with a conflict situation is outlined in Table 6. The first column, recorded activity, refers to a global or a triggering activity. The recorded activity is completed through a series of sub- or leaf activities. The leaf activity is made up of lower level tasks that need to be identified by the emergent-behavior software tool. The software tool keeps track of the values that are required of the task. These low-level characteristics are described according to the locus of control of the operator. The interrupt levels (noted in Table 6) indicate whether the software will allow the program to be interrupted to perform another task. The activities that are performed differ depending on the situation that the operator is facing.

Table 6.

Specifications: Scenario 1 Activities During Conflict Situations. This is a list of the activities that are engaged in during a conflict situation in the free flight scenario.

Recorded Activity	Leaf Activity	Interrupt Specification	Demand				Duration Specification (ms)			
			Vis.	Aud.	Cogn.	Motor	Mean	Std.	Min.	Max.
Alert Zone	None	Not interruptible	6	5.9	7	0	500	0	500	500
Recognize and understand situation	Change focus to display	Restart	6	3	6	0	2300	853	1000	4222
	Reconfigure display	Not interruptible	4	1	5.3	2.2	1200	1128	500	3000
	Understand conflict	Resume	6	0	6	0	1150	426	411	2117
Communicate Situation	None	Restart	4	5	6	2	2300	850	1000	4223
Decide Action	Change focus to display	Restart	1	4.3	6.8	2.2	2300	853	1000	4222
	Understand conflict	Not interruptible	1	1	6.8	2.2	1150	426	411	2117
	Decide action	Resume	1	1	6.8	0	7000	8000	1000	38000
Communicate action	None	Restart	0	4.9	3.7	2.2	3500	4500	1000	17000
Implement Action	Change focus to URET	Restart	7	1	4.6	1	2300	853	1000	4222
	Update flight strip	Not interruptible	4	0	4.6	4.6	16500	11838	7600	62935
Confirm Result	Change focus to display	Restart	6	3	6	0	2300	853	1000	4222
	Verify solution	Resume	1	1	6.8	0	1667	1824	411	7138

The hierarchical organization of all of the tasks to be performed by the respective operators in the system is listed in Appendix 4 for the current day operations and Appendix 5 for future free flight operations. These appendices outline the VACP requirements, the timing and standard deviations associated with each task during a handoff and not during a handoff.

First Principles examples of the human performance modeling tools, Air MIDAS and IPME, will generate scenarios that realistically represent the human performer operating in a complex multiple-controller, multiple-aircraft environment. As previously mentioned the data that the human performance modeling tool uses in its generation of response values comes from human performance and human cognition research. This research is input into the human performance modeling software tool in a number matrix from which the tool selects human performance response times. This matrix is referred to as the CRN matrix and the process whereby the tool selects from this list is termed a selection routine. The human performance modeling software tool (Air MIDAS or IPME) selects from this CRN table and uses these values in Monte Carlo simulation runs. Consistent with past research (Pisanich & Corker, 1995; Corker & Pisanich, 1995a; Corker et al., 1994; Corker & Smith, 1993), fifty Monte Carlo simulation runs were performed for each manipulation made in each modeling tool. The multiple passes through the scenario are analogous to testing multiple subjects.

Study Goals

There were two goals of the current study. The first goal was to gain a better understanding of the human performance effects of a conflict resolution between two aircraft travelling in current day ATC rules compared to free flight rules. Specifically of interest in this examination is the impact that free flight has on the timing and distance of critical events, operator actions, and operator workload in the system. The second goal of the current study was a methodological cross-comparison between two human performance modeling tools, Air MIDAS and IPME. This will not establish any diagnostic value of the particular modeling tool. Rather, the comparison will indicate whether each tool is predictive of different aspects of human performance. This will provide some insights into the validity of the current model developed given previous modeling efforts.

Method

A human performance simulation model using the human performance characteristics determined from the task decomposition of the current study was developed to examine the impact of transitioning from the current ATC operational environment to a free flight operational environment. Two candidate scenarios, one representing current day operations and one representing free flight operations, were generated that represented the human performer operating in a complex multiple controller, multiple aircraft environment using each of Air MIDAS and IPME. These models were run in parallel thus allowing accurate cross-comparison of the relative strengths of the two modeling tools and of their predictions. The scenarios were populated with performance data and tasks derived from many sources. The sources included human-in-the-loop simulation studies (Cashion et al., in press; Lozito et al., 1997), Task Analysis and WorkLoad (TAWL) prediction models of ATC and flight crew

(Hamilton, Bierbaum, & McAnulty, 1994; Rodgers & Dreschler, 1993), and previous modeling efforts (Corker, et al., 1997; Corker & Pisanich, 1995a).

Independent Variables

Two rule sets for dealing with a conflict situation were used in the current evaluation. The first rule set was consistent with the air traffic control rules of separation as outlined in Appendix 1. The second rule set also outlined in Appendix 1 was consistent with free flight rules of separation established by RTCA, Inc (1995).

The handoff condition had two levels. In the first level, the within sector condition, took place completely within one sector and did not involve a handoff between sectors. There was no communication between airspace sectors. The second level, the cross-sector condition, required a handoff between sectors requiring between sector communication.

RTCA, Inc (1995) has outlined the importance of examining the impact of unforeseen weather on the operation of the aviation environment and whether there are separation differences depending on the rules employed. As a result, two weather conditions were evaluated, one replicating normal operations with no weather concerns and one replicating an emergency communication operation related to a weather event. The experimental design can be found in Table 7.

One additional independent variable (IV) related to the operator role (the ground operators and the air operators) was included in this analysis. The workload experienced by the operator teams was expected to be different depending on the location of the team because of the change in the level of authority that is possessed by each of these teams.

Table 7

Experimental Design (Hypotheses One through Three). The following graphic represents the experimental conditions that are being studied in the current evaluation.

Locus of Control Condition	**Within/Across-sector Condition**	**Weather Condition**
ATC Rules	Within-sector	Normal
		Emergency
	Across-sector	Normal
		Emergency
	Within-sector	Normal
		Emergency
	Across-sector	Normal
		Emergency
Free Flight Rules	Within-sector	Normal
		Emergency
	Across-sector	Normal
		Emergency
	Within-sector	Normal
		Emergency
	Across-sector	Normal
		Emergency

Dependent Variables

This study set out to examine the impact on the National Airspace System's (NAS) transition to free flight. This examination involved two main dependent variables (DV). The first DV was the workload trace of the simulated operators in the NAS given the rules of flight that are followed. The second DV was concerned with the distance between the aircraft when the deconfliction maneuvers of the aircraft are commenced. The distance between the aircraft is a measure known as the Point of Closest Approach (PCA) and is measured in terms of nautical miles. The aircraft in this experiment are assumed to be traveling at the same altitude and will not engage in an action that will change their altitude. All measures can be found in Table 8.

Table 8

Model Dependent Measures.

Dependent Variable	Time	Distance	Workload	Air MIDAS	IPME
Point of Closest Approach		X		X	X
Conflict Type		X		X	X
Conflict Time	X			X	X
VACP Workload Trace			X	X	X

The point of closest approach (PCA) refers to the closest point between the aircraft prior to the aircraft making an avoidance maneuver.

Conflict type is the level of alert that is triggered by the aircraft as the aircraft approaches a violation of separation. This is inferred from the PCA distance.

Conflict time refers to the time before the conflict occurs. This is also inferred from the PCA distance.

The Visual, Auditory, Cognitive, and Psychomotor (VACP) workload trace measure refers to the four-channel, seven point measure of operator demands.

The distance-related dependent variables of interest included those aspects related to aircraft conflict. Conflict related measures included the point of closest approach. Other conflict related information that was collected includes whether an alert was triggered (conflict alert), the level of alert (types of alert) as represented by the alert zones, and the time that the conflict was to occur. Operator workload is also going to be measured. Operator workload will be indicative of the level of VACP demand associated with the manipulations made as the aircraft travels through the airspace.

Hypotheses

Three main hypotheses were generated for the current evaluation. These hypotheses examined the locus of control, the handoff and the emergency communication condition manipulations. Hypotheses one through three used Air MIDAS and IPME run in parallel, thus permitting a side-by-side comparison of the simulated operating environment. These hypotheses were evaluated using a 2 (Operator Role) x 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Weather Condition) mixed-factorial ANOVA among each of the modeling software's output (one for Air MIDAS output and one for IPME output). A cross-comparison of operational outputs predicted by the Air MIDAS and IPME software tools output from the hypotheses one through three was also of interest in the current evaluation. The dependent measures of interest were those related to timing variables of the model's action and of the operator's action, the point of closest approach (PCA) as predicted by the model, and workload characteristics as predicted by the model. The dependent measures were taken for each manipulation (independent variable) that had been made. The dependent timing, distance, and workload measures were collected 60 seconds prior to the first event.

Hypothesis #1 – Locus of Control (LOC) Condition

The nature of the responsibilities associated with the change in rule set followed by the simulated ATC and the simulated flight crew will increase simulated operator workload and simulated operator timing performance. These workload and performance differences were consistent with the predictions from Supervisory Control Theory (Sheridan, 1992). The Locus of Control (LOC) condition refers to the rules associated with the separation between aircraft. There will be two levels associated with the LOC. The first LOC is the current day or ATC rules of separation. The second level is the future or free flight LOC.

It was anticipated that closer PCA depending on the LOC to which an aircraft belongs would exist. It was expected that during ATC rules of separation there would be greater distances between aircraft as opposed to free flight rules of separation. Wickens et al. (1998) indicates that free flight rules of operation have the potential of increasing the consequences of an airspace conflict. A measure of time to conflict in current day operations and resulting control input by the simulated operator was compared with time to conflict in free flight operations and resulting control input by the simulated operator was evaluated.

Dependent variables associated with simulated operator decision, time of simulated operator decision, and the workload trace (Laudeman et al., 1998; Lozito et al., 1997; Wyndemere, 1996), between the simulated ATC crew and the simulated flight crew were also expected to show a differences associated with the LOC. The simulated operator decisions were anticipated to be different in each LOC because the nature and responsibilities of the operator are different with the different rule set. This difference in responsibility results in the simulated operator making different decisions. The procedural sequence of tasks was different between the two LOCs.

Hypothesis #2 – Handoff Condition

The handoff condition was defined as the time that the controller must handoff the aircraft to another airspace sector controller (U.S. Department of Transportation, 1998). The first level was a within-sector condition where no handoff is scheduled to occur between sectors. The aircraft of interest was not scheduled to cross into a new airspace sector. The second level was a between sector condition where the controller simulated ATC was required to hand the aircraft of interest off to a new sector.

It was hypothesized that the DV of point of closest approach, time of point of closest approach and the conflict alert levels would be unaffected by the handoff condition. It was predicted that workload from the simulated flight deck perspective would be increased when the simulated flight deck was operating under current ATC rules as measured by the mean VACP workload values.

Hypothesis #3 – Emergency Condition

The emergency communication was defined as being an unexpected weather event impacting the flight system thus causing an unforeseen communication between the ground crew and the flight crew. This unexpected event would take the form of a third aircraft notifying the simulated ATC of a weather disturbance along the path traveled by the aircraft of interest, in this case, the Ownship. Two conditions were examined with emergency communication. The first condition was that no emergency communication would occur during the airspace sector pass-through. The second condition possessed an emergency communication detailing the location of the airspace concern.

It was hypothesized that workload of all the simulated operators in the system (system-wide workload) would be increased when the simulated aircraft was confronted with an airspace concern. This was expected because previous research has shown that changes in operator expectations result in workload increases (Degani, et al., 1996). Airspace sector pass-through time would be lower when no emergency communication exists because the simulated aircraft does not need to make changes to the flight plan. When an emergency does exist however, the simulated aircraft would be required to make a flight plan modification.

The variable of PCA was also hypothesized to be affected by an emergency weather contact. When an emergency weather communication occurs, an effect was expected on the PCA. It was anticipated that the emergency event would have an interrupting effect on the simulated operator in each of the systems and that the PCA distance would be reduced when there was operating in an emergency condition.

Modeling Tool Cross-Comparison

A comparison of the output of the modeling tools Air MIDAS and IPME was also of interest in this experiment. Air MIDAS has been designed with the goal of being able to accurately represent processes such as working memory, task scheduling, sensation and perception, cognition, and motor output (Laughery & Corker, 1997). IPME has been designed with similar but different goals. IPME has been designed to effectively represent individual and team operation through its HLA (see Figure 6). No difference on VACP workload between Air MIDAS and IPME was expected because they use similar characteristics. Consistencies were expected between the modeling tools on the dimensions of workload trace measures and on PCA.

Analyses

A standard set of descriptive analyses was performed for each of the Air MIDAS and IPME simulation sets as represented by the manipulations in the independent variables list[1]. These data show the mean performance that may be expected of operators performing under the constraints imposed by the scenarios as well as the respective standard deviations. Data collection was triggered from a generic start point at a point 60 seconds prior to the first event in the scenario to the conclusion of the final event maneuver. A 2 (Operator Role) x 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) mixed-factorial ANOVA was performed using the average workload (VACP) output of the Air MIDAS model. A second 2 (Operator Role) x 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) mixed-factorial ANOVA was performed using the average workload output of the IPME model. A cross-comparison between the Air MIDAS and IPME was completed by observing the differences between the output of the two separate analyses of variance and through a comparison of the trends of the means. A 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Weather Condition) factorial ANOVA on PCA data was also completed for each Air MIDAS and for IPME output.

Results

The output of each of the Air MIDAS and the IPME software tools was used to evaluate the NAS' transition to free flight. Each software tool was first used individually to predict the system effects associated with free flight. This was performed because differences were expected between the models and that these differences may have

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[1] All statistical tests used SPSS Apple/Macintosh version 6.1 statistical software package.

resulted in hiding some significant results as predicted by an individual system. It is important to see the difference between the models in order to obtain an increased understanding of human performance and the influences on human performance as predicted by a human performance modeling tool. The results of the current evaluation will be described in two sections according to the dependent variable being measured. With any human performance modeling tool, the variability that is associated with the model's common random number (CRN) generator is known and the range from which the modeling software selects is limited. This results in a small data set that is being sampled at very high rates resulting in strongly significant statistical tests with very small differences between mean values (Banks, 1998). Human performance model developers face a potential statistical paradox in attempting to gain insight into a model's predicted effect on behavior. Two main conceptualizations can affect a model developer's choice of an appropriate statistical test for a human performance model (Banks, 1998). The first is that the model developer can conceptualize the model generating run as a test of many individuals being tested across a number of different manipulations to examine the manipulation's effect on the operator's predicted performance. Many runs can be performed each taking effect of a single change within the experiment and an evaluation of the effect of this change on operator performance can be made. In designing a human performance modeling experiment in this way, the model developer will be faced with a liberal criterion upon which to judge the human performance effects of an experimental manipulation. The second is that the design can be thought of as a simulated, individual, human operator being tested a number of times in a repeated-measures fashion. This approach to evaluating simulation output is consistent with the approach to simulation output analysis proposed by Naylor and Finger (1967). In taking this approach to human performance modeling, the model developer is looking at the numbers as being a representation of a single operator's performance as response values are being generated from a similar pool of subject response data contained within the CRN generator. The current statistical approach that was decided on was a combination of the two approaches explained above, the repeated-measures approach to inter-model comparison and the between-subjects approach, a mixed factorial approach. This statistical approach was decided upon after each of the three methods outlined above were performed on the human performance model's output data of the scenarios designed for the present study.

The first statistical approach considered was a completely between-subjects design where an average of operator performance was taken for each of the individual operators' workload in the simulated NAS. This first approach resulted in the most liberal statistical approach thus resulted in the largest number of degrees of freedom. The second was a mixed-factorial design. An average workload value was created for each of two operator locations, the ground and the air with an average of the first half of the model runs, run one through run twenty-five being the first factor and runs twenty six though run fifty being the second factor. This second approach resulted in the most conservative statistical approach, thus possessed the smallest degrees of freedom. The third approach considered was a moderately conservative statistical approach (between the first and the second approaches) that broke the comparison down by the independent variable's impact on operator workload with the first level being representative of the no manipulation condition with the second level being the manipulation condition. This third (moderate) approach is the statistical approach used in the current evaluation.

Where appropriate, post-hoc Tukey tests were performed. Only results significant at $p \leq .05$ are discussed.

Workload Demand

The following section indicates the descriptive data of the modeled human performance effects on the simulated operator as indicated by the average VACP simulated operator workload values. This will be followed by the presentation of the ANOVA results indicating the effect of the manipulation on modeled human performance under each of the modeling software tools, Air MIDAS and IPME. The modeled workload measures on a zero to seven point scale (zero represents the lowest workload and seven represents highest workload) were taken at the conclusion of the simulation run and an average of each of the modalities was taken for the respective amount of modeled workload according to the condition under study. The main events of interest in conflict resolution were the locus of control differences, the handoff effects, and the unexpected weather condition effects on the avoidance of upcoming airspace conflicts.

Table 9 demonstrates a side-by-side comparison of the minimum, maximum, mean and standard deviation workload values output provided by each modeling tool according to the manipulation made in the current study. Note that all ground and flight-crew references that are made refer to simulated ground-crew and simulated flight-crew.

Table 9

Mean Workload Values by Modeling Tool.

Role	Locus of Control	Handoff	Emergency	Air MIDAS			
				M	SD	Min	Max
Ground	Current	No Handoff	No Emergency	0.78	0.0165	0.74	0.82
			Emergency	0.84	0.0194	0.80	0.90
		Handoff	No Emergency	0.85	0.0232	0.79	0.89
			Emergency	0.88	0.0229	0.84	0.93
	Free Flight	No Handoff	No Emergency	0.69	0.0153	0.66	0.73
			Emergency	0.75	0.0223	0.70	0.79
		Handoff	No Emergency	0.78	0.0354	0.72	0.85
			Emergency	0.84	0.0738	0.70	0.95
Air	Current	No Handoff	No Emergency	0.67	0.0116	0.65	0.69
			Emergency	0.70	0.0177	0.68	0.77
		Handoff	No Emergency	0.72	0.0250	0.69	0.84
			Emergency	0.75	0.0182	0.72	0.79
	Free Flight	No Handoff	No Emergency	1.44	0.0663	1.29	1.55
			Emergency	1.59	0.0618	1.44	1.72
		Handoff	No Emergency	1.56	0.1170	1.33	1.77
			Emergency	1.52	0.0649	1.38	1.67

Role	Locus of Control	Handoff	Emergency	IPME			
				M	SD	Min	Max
Ground	Current	No Handoff	No Emergency	1.80	0.0387	1.73	1.89
			Emergency	1.85	0.0358	1.79	1.94
		Handoff	No Emergency	1.84	0.0395	1.75	1.92
			Emergency	1.90	0.0392	1.80	1.99
	Free Flight	No Handoff	No Emergency	2.00	0.0328	1.94	2.08
			Emergency	2.04	0.0351	1.95	2.15
		Handoff	No Emergency	2.11	0.0353	2.04	2.19
			Emergency	2.15	0.0336	2.07	2.21
Air	Current	No Handoff	No Emergency	0.55	0.0951	0.34	0.76
			Emergency	0.58	0.0960	0.40	0.79
		Handoff	No Emergency	0.64	0.0831	0.47	0.84
			Emergency	0.71	0.0986	0.54	0.93
	Free Flight	No Handoff	No Emergency	1.74	0.1408	1.45	2.13
			Emergency	1.77	0.1423	1.50	2.14
		Handoff	No Emergency	1.90	0.031	1.67	2.22
			Emergency	1.95	0.1094	1.73	2.17

Air MIDAS Specific Analyses

A 2 (Operator Role) by 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) mixed-factorial ANOVA was performed using the average workload (VACP) output from the Air MIDAS software. The workload values associated with the main effect of LOC condition demonstrated in Figure 10 indicates that the current day rules of flight possesses lower simulated workload values than the free flight workload values. The ANOVA table demonstrated in Table 10 depicts that this difference is statistically significant (F (1, 98) = 11929.46, $p \leq .0001$). This indicates that the simulated crew workload in the NAS is significantly increased with the transition to free flight rules from the current rule set. When examining the effect on workload of the LOC within the operator's role, it can be seen that LOC significantly interacts with the role of the simulated operator (F (1, 98) = 16947.72, $p \leq .0001$). There is a decline in predicted simulated workload from the simulated ground-crew to the simulated flight-crew when operating under current day rules of operation. Upon evaluation of the means, it can be seen that this pattern of decline in workload between the ground to the air is reversed under free flight operations. The simulated flight-crew has a greater increase in predicted workload in free flight operations.

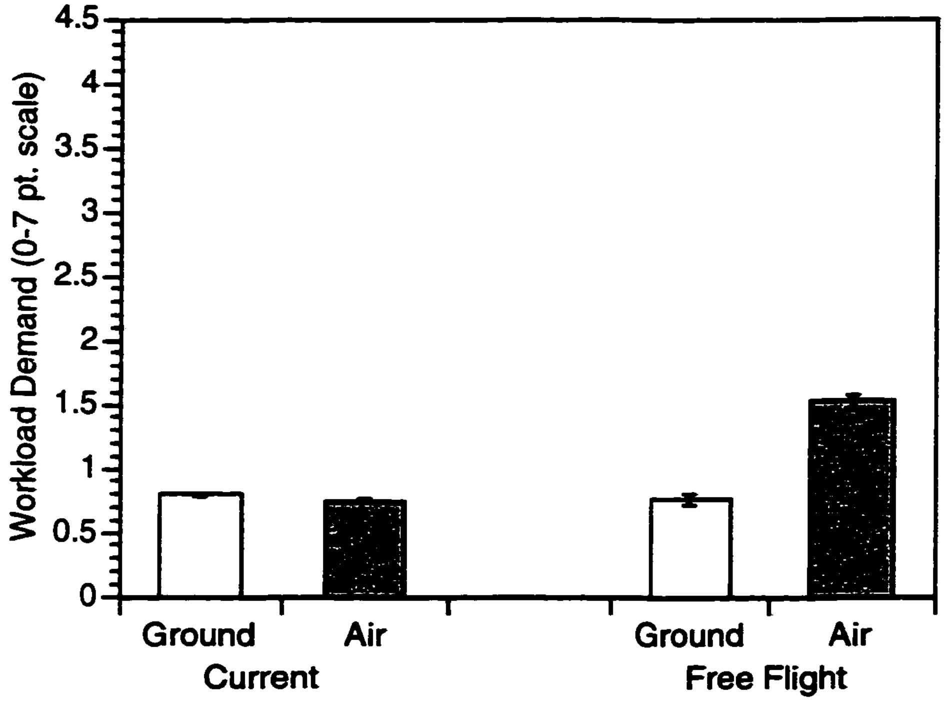

Figure 10. Air MIDAS workload - Role by Locus of Control (LOC) condition. The error bars represent one standard deviation around the mean (for some means no error bars represent no discernable difference between means).

Table 10.

Repeated Measures Air MIDAS ANOVA Table. Repeated Measures ANOVA output from the Air MIDAS predictions of simulated operator performance. Factor 1 = Locus of Control (LOC made up of Current or Free Flight), Factor 2 = Handoff Condition made up of No Handoff or Handoff), Factor 3 = Emergency Condition made up of No Emergency or Emergency).

	SS	DF	MS	F	Sig. of F
Within + Residual	0.23	98	0.00		
Role	20.17	1	20.17	8448.44	0.000
Within + Residual	0.23	98	0.00		
Factor 1 (LOC)	27.75	1	27.75	11929.46	0.000
Role x Factor1	39.42	1	39.42	16947.72	0.000
Within + Residual	0.24	98	0.00		
Factor 2 (Handoff)	0.64	1	0.64	257.28	0.000
Role x Factor2	0.060	1	0.06	22.56	0.000
Within + Residual	0.19	98	0.00		
Factor 3 (Emerg)	0.50	1	0.50	250.50	0.000
Role x Factor3	0.00	1	0.00	.36	0.549
Within + Residual	0.26	98	0.00		
Factor1 x Factor2	0.00	1	0.00	0.73	0.395
Role x Factor1 x Factor2	0.03	1	0.03	10.00	0.002
Within + Residual	0.20	98	0.00		
Factor1 x Factor3	0.03	1	0.03	12.40	0.001
Role x Factor1 x Factor3	0.00	1	0.00	0.48	0.488
Within + Residual	0.22	98	0.00		
Factor2 x Factor3	0.14	1	0.14	61.08	0.000
Role x Factor2 x Factor3	0.08	1	0.08	33.48	0.000
Within + Residual	0.22	98	0.00		
Fact1 x Fact2 x Fact3	0.09	1	0.09	38.87	0.000
Role x Fact1 x Fact2 x Fact3	0.15	1	0.15	70.10	0.000

It can also be seen in Table 10 that there is a main effect of the handoff condition on simulated operator workload (F (1, 98) = 257.28, $p \leq 0.0001$). Furthermore, the role of the simulated operator does appear to differentially impact the workload of the operator (F (1, 98) = 22.56, $p \leq 0.0001$). This significant difference can be seen in Figure 11. Although anticipated, and as can be seen in Table 10, there is no significant two-way interaction on NAS overall workload among the LOC and the handoff condition (F (1, 98) = 0.73, $p > 0.05$). This is evidence that the handoff condition does not produce an effect on operator workload as predicted by Air MIDAS depending on whether the NAS is under ATC as compared to free flight control when a handoff is occurring. Figure 11 demonstrates that when examining the role of the operator, a significant impact on system workload occurs with an increase in the simulated operator workload in the handoff over the no handoff condition depending on the rules of flight. There is an increase in ground-crew workload in the handoff condition over the no handoff condition when operating under both current day and free flight operations. There is also an increase in aircrew workload in the handoff condition over the no handoff condition but only in current day operations. This difference does not exist when operating under free flight conditions for the flight crew (see Figure 11). The Role x LOC x Handoff interaction was significant (F (1, 98) = 10.00, $p \leq .01$).

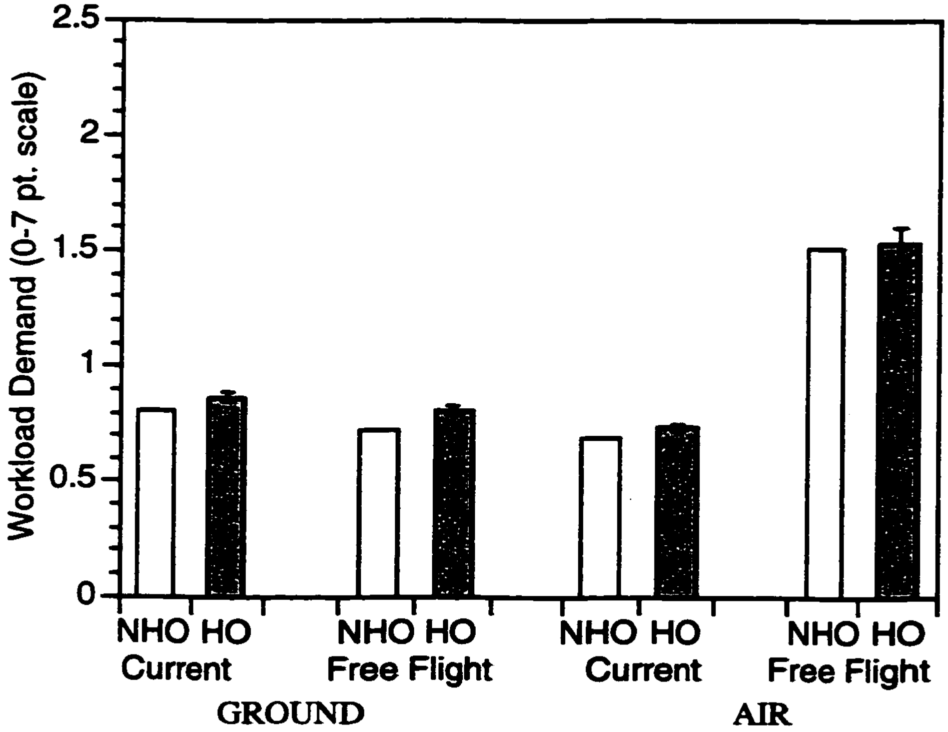

Figure 11. Air MIDAS Workload - Operator Role (Ground or Air) by Locus of Control (LOC; Current or Free Flight) by Handoff (No Handoff, Handoff) condition. The error bars represent one standard deviation around the mean (for some means no error bars represent no discernable difference between means). NHO refers to the No Handoff and HO refers to the Handoff condition.

There is a significant effect of the emergency condition on NAS workload (F (1, 98) = 22.56, $p \leq 0.0001$). There is no significant interaction among emergency and the role of the simulated operator (F (1, 98) = 0.36, $p > 0.55$). Figure 12 demonstrates that there is a predicted workload increase from the no emergency to the emergency condition when operating under current day rules. This significant increase does not exist under the free flight condition when moving from the no emergency to the emergency condition. As anticipated, this two-way interaction between the LOC and the emergency condition was found to be significant (F (1, 98) = 12.40, $p \leq .001$).

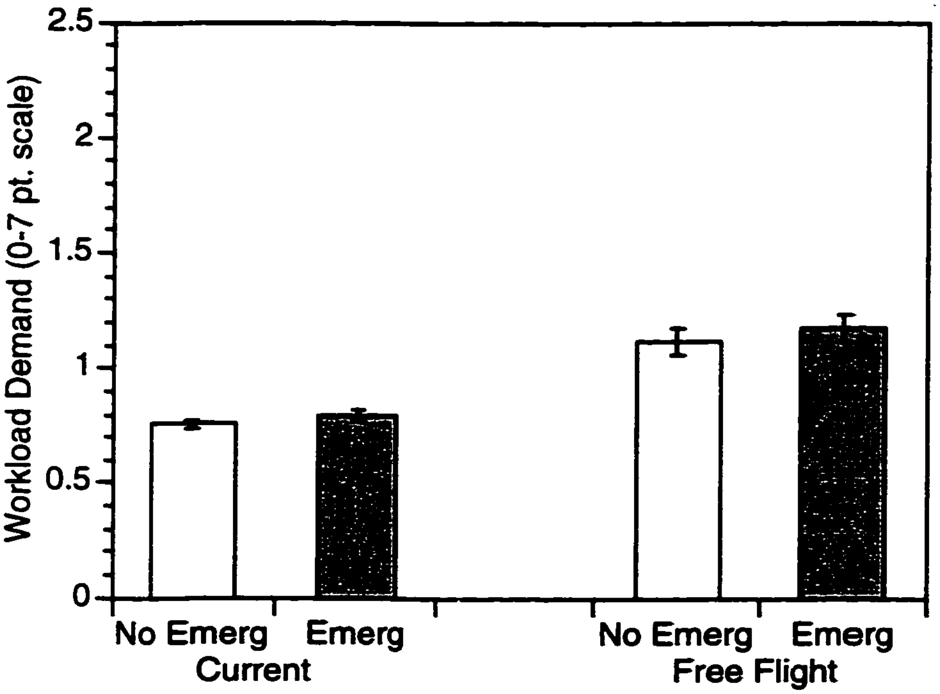

Figure 12. Air MIDAS Workload - Locus of Control (Current or Free Flight) by Emergency (No Emergency, Emergency) condition. The error bars represent one standard deviation around the mean. No Emerg refers to the No Emergency and Emerg refers to the Emergency condition.

A significant three-way interaction existed on the predictions made by Air MIDAS among locus of control, the handoff and the emergency conditions (F (1, 98) = 38.87, $p \leq .0001$). As demonstrated on Table 10, the emergency condition does not appear to affect the operator's workload depending on the LOC and the role of the operator (F (1, 98) = 0.48, $p > 0.05$). This is providing some evidence that using the Air MIDAS software, the role of the operator is removing some of the predicted operator variability when the role is being combined with the other manipulations in the current study.

A four-way interaction exists among the workload predictions from Air MIDAS among the operator's Role (ground or air crew), the LOC, the handoff condition and the emergency condition (F (1, 98) = 70.10, $p \leq .0001$). This interaction although interesting will not be focussed on in the results section because this difference exists due to the scheduling mechanism within the computer software. It is being mentioned here for IPME comparative purposes.

IPME Specific Analyses

A second 2 (Operator Role) x 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) mixed-factorial ANOVA was performed using the average (VACP) workload output of the IPME model. The workload values associated with the main effects of LOC condition demonstrated in Table 9 indicates that the current day rules of flight possesses lower simulated workload values than the free flight workload values (F (1, 98) = 12807.08, $p \leq .0001$). When examining the effect of the LOC within the operator's role, it can be seen that LOC significantly affects the operator workload depending on the role of the simulated operator (F (1, 98) = 6087.81, $p \leq .0001$). The simulated ground-crew appear to have less predicted workload increases when moving from current day rules of separation to free flight rules of separation than the simulated air-crew. It can be seen in Figure 13 that there is increased workload on an operator during a handoff as opposed to a no handoff condition. When evaluated statistically, this interaction effect is indeed significant (F (1, 98) = 315.47, $p \leq .0001$). It is also apparent from the ANOVA table outlined in Table 11 that the ground crew possesses increased workload over the simulated flight crews when dealing with a handoff (F (1,98) = 25.50, $p \leq 0.0001$). The difference between the no handoff and the handoff is greater for the air than the ground. It can be seen in Figure 14 that there is increased workload on an operator during an emergency condition as compared to a no emergency condition. The effect of the emergency condition on simulated operator workload is also significant (F (1, 98) = 72.34, $p \leq 0.0001$). There is no significant difference on the emergency condition's effect on workload dependent upon whether the operators are ground-based or air-based.

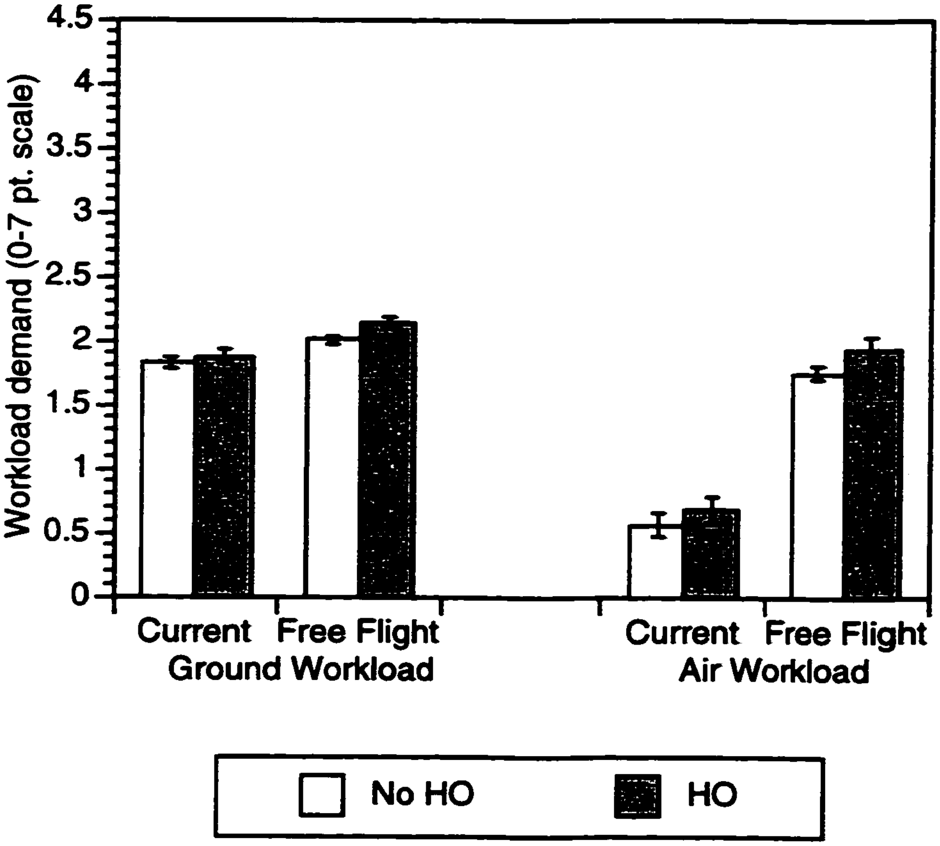

Figure 13. IPME Workload - Operator Role (Ground, Air) by Locus of Control (Current, Free Flight) by Handoff (No Handoff, Handoff) condition. The error bars represent one standard deviation around the mean (for some means no error bars represent no discernable difference between means). No HO refers to the No Handoff and HO refers to the Handoff condition.

Table 11.

Repeated Measures Integrated Performance Modeling Environment (IPME) ANOVA Table. Repeated Measures ANOVA output from the IPME predictions of simulated operator performance. Factor 1 = Locus of Control (LOC made up of Current or Free Flight), Factor 2 = Handoff Condition made up of No Handoff or Handoff), Factor 3 = Emergency Condition made up of No Emergency or Emergency).

	SS	DF	MS	F	Sig. of F
Within + Residual	0.77	98	0.01		
Role	106.88	1	106.88	13650.40	0.000
Within + Residual	0.80	98	0.01		
Factor 1 (LOC)	104.18	1	104.18	12807.08	0.000
Role x Factor1	49.52	1	49.52	6087.81	0.000
Within + Residual	0.77	98	0.01		
Factor 2 (Handoff)	2.48	1	2.48	315.47	0.000
Role x Factor2	0.20	1	0.20	25.50	0.000
Within + Residual	0.59	98	0.01		
Factor 3 (Emerg)	0.44	1	0.44	72.34	0.000
Role x Factor3	0.00	1	0.00	0.34	0.564
Within + Residual	0.64	98	0.01		
Factor1 x Factor2	0.20	1	0.20	31.27	0.000
Role x Factor1 x Factor2	0.00	1	0.00	0.57	0.451
Within + Residual	0.87	98	0.01		
Factor1 x Factor3	0.00	1	0.00	0.54	0.465
Role x Factor1 x Factor3	0.00	1	0.00	0.39	0.535
Within + Residual	0.59	98	0.01		
Factor2 x Factor3	0.02	1	0.02	3.26	0.74
Role x Factor2 x Factor3	0.01	1	0.01	1.19	0.279
Within + Residual	0.61	98	0.01		
Factor1 x Factor 2 x Factor3	0.00	1	0.00	0.14	0.712
Role x Fact1 x Fact2 x Fact3	0.00	1	0.00	0.00	0.979

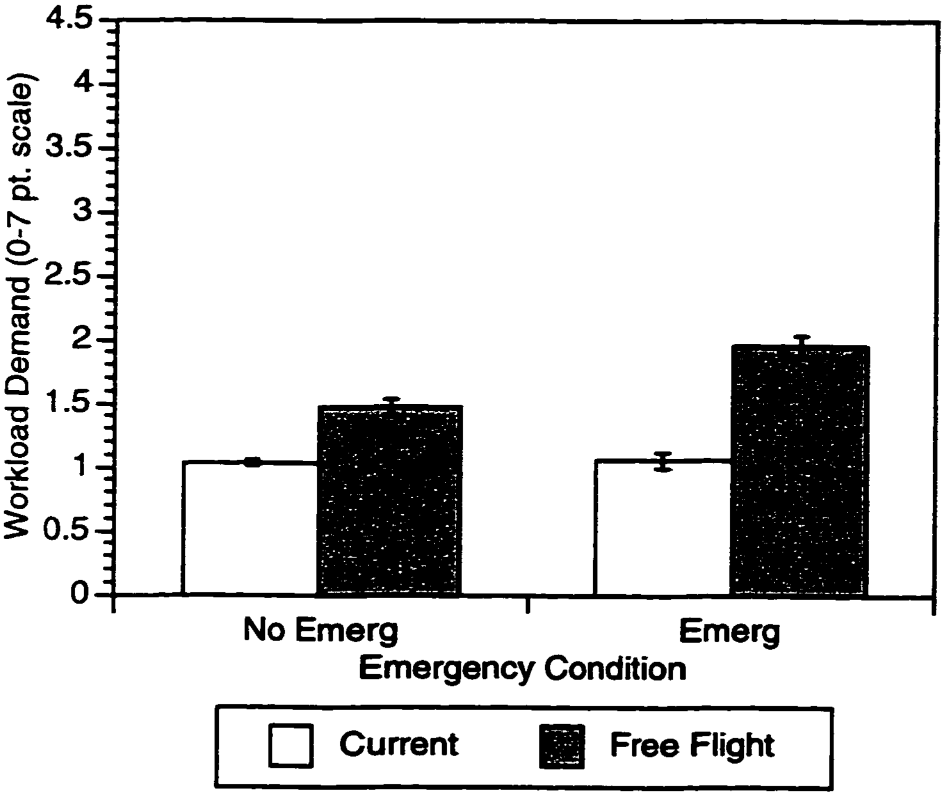

Figure 14. IPME Workload - Locus of Control (Current or Free Flight) by Emergency (No Emergency, Emergency) condition. The error bars represent one standard deviation around the mean (for some means no error bars represent no discernable difference between means).

There is a significant two-way interaction on overall NAS workload between the LOC and handoff ($\underline{F}$ (1, 98) = 31.27, $\underline{p} \leq .0001$). In current day operations, the no handoff condition appears to require slightly less overall workload than the handoff condition. This is a good verification that the current day operations are demonstrating baseline behavior. There is also a similar pattern in the free flight condition with the no handoff condition requiring less workload than the handoff condition. The three-way interaction of Role x LOC x Handoff was not significant. Although anticipated, there were no other higher level interactions using the IPME software predictions of operator performance even though some of these higher level interactions were existent using the Air MIDAS software.

Point of Closest Approach

A second dependent variable collected included the point of closest approach (PCA). Recall that the PCA is the closest point between the simulated Ownship and the simulated Intruder before the aircraft begin their avoidance maneuver. This variable served to compare the two models' structural performance, that is the degree to which the models vary in the model generation scenario. The grand means and standard deviations output from both Air MIDAS and IPME can be found in Table 12.

Table 12.

Point of Closest Approach (PCA) Grand Means in Nautical Miles by Modeling Tool. High level means, and standard deviations of the point of closest approach between aircraft.

Variable	Level	Air MIDAS		IPME	
		M	SD	M	SD
Locus of Control	Current	5.86	0.58	16.67	0.63
	Free Flight	6.57	0.42	4.93	0.44
Handoff	No Handoff	5.83	0.61	10.83	5.95
	Handoff	6.60	0.31	10.77	5.85
Emergency	No Emergency	6.12	0.54	10.83	5.93
	Emergency	6.31	0.67	10.77	5.87

Air MIDAS Specific Analyses

A 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) factorial ANOVA was performed using the average PCA distances output from the Air MIDAS software. The PCA distances associated with the main effect of LOC condition demonstrated in Table 13 indicates that current day operations will have closer PCA than will free flight operations. The ANOVA table demonstrated in Table 14 depicts that this difference is significant when evaluated statistically (F (1,49) = 968.49, $p \leq 0.0001$). Air MIDAS also predicts there to be significantly closer PCA in the handoff condition than in the no handoff condition (F (1,49) = 928.85, $p \leq 0.0001$). This means that as the simulated operators are facing increased demands, there is an effect on their simulated performance that increases the time that they take to respond to the handoff condition. Air MIDAS predicts closer PCA in the emergency condition than in the no emergency condition (F (1,49) = 69.09, $p \leq 0.0001$). This means that as the simulated operators are facing increased demands, there is also an effect on their simulated performance that increases the time that they take to respond to the emergency condition.

Table 13.

Air MIDAS Point of Closest Approach (PCA) Means in Nautical Miles by Condition. Experimental conditions included Locus of Control (LOC; Current Day Rules, Free Flight Rules), Handoff Condition (No Handoff, Handoff), and Weather Condition (No Emergency, Emergency). LOC1 refers to the Current Day Rules, LOC2 refers to the Free Flight Rules, No HO refers to the No Handoff and HO refers to the Handoff condition.

		Air MIDAS			
Variable	Name	M	SD	Min	Max
PCA	Overall PCA	6.221	0.622	5.74	6.78
LOC1	Current Day Rules	5.863	0.582	5.52	6.39
No HO	within	5.316	0.215	4.91	5.84
WEATHER	no emergency	5.345	0.206	4.90	5.86
WEATHER	emergency	5.286	0.222	4.92	5.82
HO	between	6.410	0.176	6.12	6.93
WEATHER	no emergency	6.408	0.192	6.08	6.98
WEATHER	emergency	6.413	0.159	6.16	6.88
LOC 2	Free Flight Rules	6.579	0.422	5.96	7,16
No HO	within	6.354	0.420	5.62	7.02
WEATHER	no emergency	6.078	0.310	5.35	6.97
WEATHER	emergency	6.629	0.326	5.90	7.07
HO	between	6.804	0.281	6.30	7.29
WEATHER	no emergency	6.660	0.212	6.27	7.27
WEATHER	emergency	6.949	0.269	6.34	7.30

Table 14.

Air MIDAS Point of Closest Approach (PCA) ANOVA Table. Factor 1 = Locus of Control (LOC made up of Current or Free Flight), Factor 2 = Handoff Condition made up of No Handoff or Handoff), Factor 3 = Emergency Condition made up of No Emergency or Emergency).

	SS	DF	MS	F	Sig. Of F
Within + Residual	2.59	49	0.05		
Factor 1 (LOC)	51.28	1	51.28	968.49	0.000
Within + Residual	3.15	49	0.06		
Factor 2 (Handoff)	56.69	1	56.69	928.85	0.000
Within + Residual	2.75	49	0.06		
Factor 3 (Em)	3.87	1	3.87	69.09	0.000
Within + Residual	2.79	49	0.06		
Factor1 by Factor2	10.37	1	10.37	181.82	0.000
Within + Residual	2.40	49	0.05		
Factor1 by Factor3	5.01	1	5.01	102.39	0.000
Within + Residual	3.54	49	0.07		
Factor2 by Factor3	0.24	1	0.24	3.37	0.073
Within + Residual	2.85	49	0.06		
Factor1 by Factor2 by Factor3	0.66	1	0.66	11.41	0.001

There are a number of two-way interactions associated with the PCA from the Air MIDAS predictions. Upon examination of the means in Table 13, it can be seen that there are larger PCA distances when a handoff is occurring than when no handoff is occurring and that this difference is increased in the free flight condition over the current day rules of separation. The differences between the no handoff and the handoff condition in free flight are not significantly different from one another while the differences between the no handoff and the handoff condition in current day separation is significant. The LOC by handoff interaction can be seen in Figure 15. The handoff condition interacted with the LOC with the handoff condition possessing significantly less PCA distance in the current day handoff condition as compared with the current day, no handoff condition. This pattern is reversed in free flight with the free flight no handoff condition possessing less PCA distances than the free flight handoff condition. As seen in the ANOVA table, there is a significant difference among the LOC and the handoff condition ($\underline{F}$ (1,49) = 181.82, $\underline{p} \leq 0.0001$). It can be seen by examining the means in Figure 16 that little difference exists among the no emergency and emergency conditions. There does however appear to be a difference in the PCA between the no emergency and the emergency conditions under free flight rules. Each of the no emergency and emergency conditions under current day does appear to be different than under free flight. As seen in the ANOVA table, there is a significant difference among the LOC and the emergency condition ($\underline{F}$ (1,49) = 3.37, $\underline{p} \leq 0.0001$).

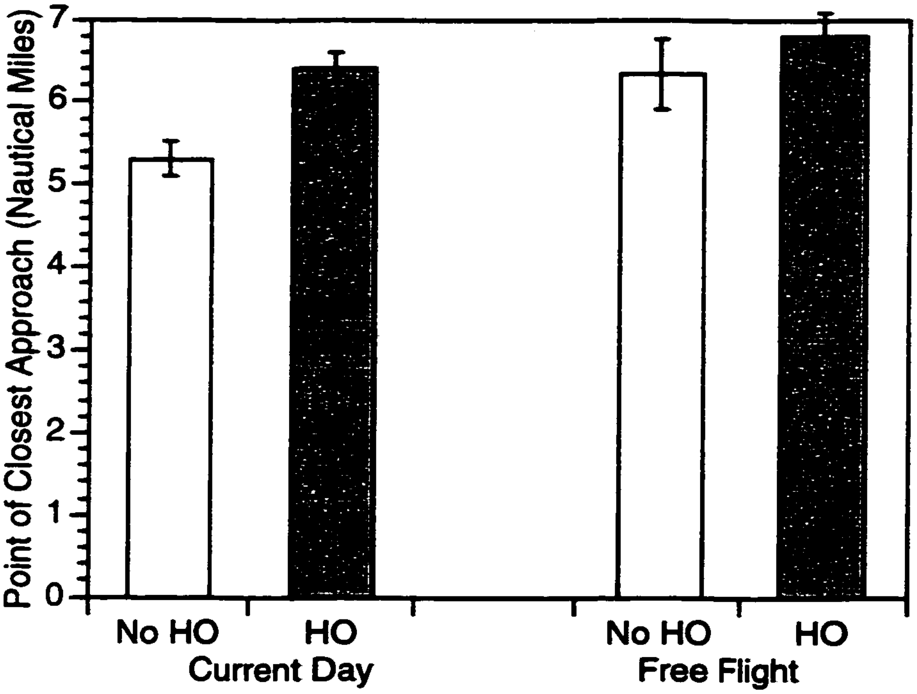

Figure 15. Air MIDAS Point of Closest Approach (PCA) in Nautical Miles - Locus of Control (Current or Free Flight) by Handoff (No Handoff, Handoff) Interaction. The error bars represent one standard deviation around the mean. No HO refers to the No Handoff and HO refers to the Handoff condition.

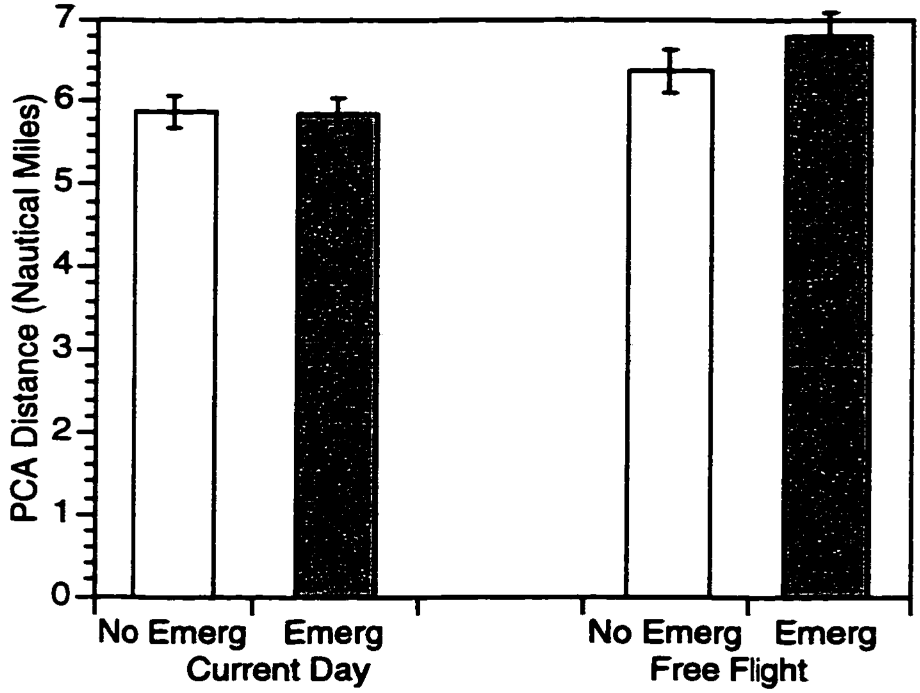

Figure 16. Air MIDAS Point of Closest Approach (PCA) in Nautical Miles - Locus of Control (Current, Free Flight) by Emergency (No Emergency, Emergency) Interaction. The error bars represent one standard deviation around the mean. No Emerg refers to the No Emergency and Emerg refers to the Emergency condition.

IPME Specific Analyses

A second 2 (Locus of Control) x 2 (Handoff Condition) x 2 (Emergency Condition) factorial ANOVA was performed using the PCA output of the IPME model. The PCA distances associated with the main effects of LOC condition demonstrated in Table 15 indicate that the current day rules of flight possesses greater simulated PCA distances than the free flight workload values. The ANOVA table depicted in Table 16 demonstrates this difference to be significant (F (1, 49) = 36104.24, $p \leq .0001$). This distance-related information is representative of the changes that will be associated with free flight given the responses required in the current rule set to the conflict situation. Both responses involved the same heading change in response to the conflict situation given the provision of the alert information. This is occurring because of the procedural changes that are associated with free flight. As seen on the ANOVA table listed in Table 16, the handoff condition and the emergency main effects and all interactions among these variables were not significantly different from each other using the IPME prediction.

Table 15.

<u>IPME Point of Closest Approach (PCA) Means in Nautical Miles by Condition.</u> Experimental conditions included Locus of Control (LOC; Current Day Rules, Free Flight Rules), Handoff Condition (No Handoff, Handoff), and Weather Condition (No Emergency, Emergency). LOC1 refers to the Current Day Rules, LOC2 refers to the Free Flight Rules, No HO refers to the No Handoff and HO refers to the Handoff condition.

		IPME			
Variable	Name	M	SD	Min	Max
PCA	Overall PCA	10.803	5.897	9.64	12.16
LOC1	Current Day Rules	16.668	0.636	15.15	18.17
No HO	within	16.740	0.616	15.39	18.17
WEATHER	no emergency	16.768	0.538	15.72	18.05
WEATHER	emergency	16.712	0.689	15.05	18.28
HO	between	16.595	0.651	14.90	18.16
WEATHER	no emergency	16.692	0.638	15.14	18.36
WEATHER	emergency	16.499	0.654	14.66	17.96
LOC2	Free Flight Rules	4.939	0.444	4.12	6.15
No HO	within	4.919	0.465	4.08	6.36
WEATHER	no emergency	4.940	0.485	4.11	6.79
WEATHER	emergency	4.899	0.448	4.04	5.93
HO	between	4.959	0.423	4.17	5.93
WEATHER	no emergency	4.947	0.465	4.12	5.97
WEATHER	emergency	4.971	0.381	4.21	5.89

Table 16.

Integrated Performance Modeling Environment (IPME) Point of Closest Approach (PCA) ANOVA Table. Factor 1 = Locus of Control (LOC made up of Current or Free Flight), Factor 2 = Handoff Condition (made up of No Handoff or Handoff), Factor 3 = Emergency Condition (made up of No Emergency or Emergency).

	SS	DF	MS	F	Sig. of F
Within + Residual	18.87	49	0.38		
Factor 1 (LOC)	13756.21	1	13756.21	36104.24	0.000
Within + Residual	10.98	49	0.22		
Factor 2 (Handoff)	0.28	1	0.28	1.24	0.271
Within + Residual	11.87	49	0.24		
Factor 3 (Em)	0.45	1	0.45	1.85	0.180
Within + Residual	13.66	49	0.28		
Factor1 by Factor2	0.84	1	0.84	3.02	0.088
Within + Residual	16.53	49	0.34		
Factor1 by Factor3	0.33	1	0.33	0.99	0.324
Within + Residual	15.21	49	0.31		
Factor2 by Factor3	0.03	1	0.03	0.11	0.743
Within + Residual	14.38	49	0.29		
Factor1 by Factor2 by Factor3	0.26	1	0.26	0.87	0.355

Modeling Tool PCA Comparison

As can be seen on Table 12, the Air MIDAS software indicates a lower PCA value under current day rules of separation than when using IPME. This difference is reversed however when looking at free flight. The means in the free flight separation are higher with the Air MIDAS prediction as opposed to the IPME prediction. Care must be taken when looking at the overall means listed in the Table 12 because some information on the PCA may be lost as a result of interactions between the LOC, the handoff, and the emergency. This is well seen when looking at the mean values within the IPME prediction of PCA and the respective interactions among the variables in each of Air MIDAS and IPME. A graphic of these interactions and the relative effect using the respective human performance model can be seen in Figure 17. Figure 17 demonstrates that the Air MIDAS model provides a much more consistent behavioral pattern surrounding the non-transgression zone, the 5 nautical mile protected zone as compared with the IPME model predictions. One half of the PCA distances appears to increase using the IPME while the same one half of PCA using the Air MIDAS software became closer together. The condition that represents this half of the simulation is the current day rules of separation. On the other one half of the simulation trials, there is a reversal where the predicted PCA distances become closer together using the IPME over those predicted by Air MIDAS.

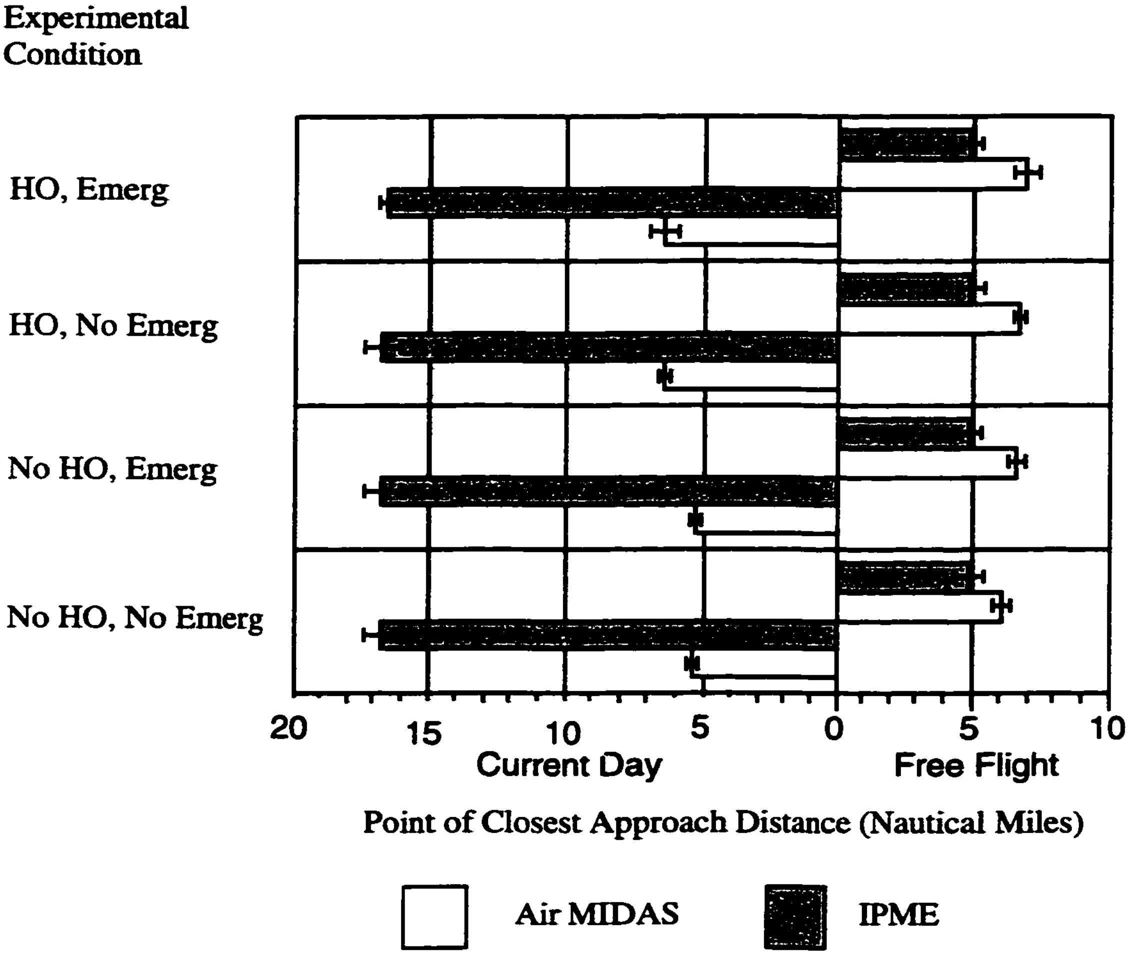

Figure 17. Point of Closest Approach (PCA) Distance (Nautical Miles) - Model Used (Air MIDAS or IPME). This graphic demonstrates the difference in the PCA component of the model generating structure. No HO refers to the 'No Handoff' condition, HO to the Handoff condition, No Emerg to the No Emergency condition, and Emerg to the Emergency condition.

A comparison between Air MIDAS and IPME along the dimension of PCA in current day rules of operations is unfortunately not possible because the rules that were employed in programming the current day operations were different. Air MIDAS used a degree of heading that was based on the distance, speed, and heading to conflict point between the simulated Ownship and the simulated Intruder aircraft. IPME used a ten-degree heading change irrespective of the rules of flight. This is the reason for the dramatic differences in the PCA distances demonstrated in Figure 18 in the current operational procedures between the two models. The predictions provided by Air MIDAS do not indicate any separation violations between aircraft thus possess only a non-transgression zone alert (Figure 1). The IPME produced a reversed pattern to the one produced by Air MIDAS with higher PCA values in current day operations as compared to free flight operations. In fact, the IPME predicts the aircraft to be within a transgression zone level of alert (Figure 1). The current day operations in the no handoff condition possess greater PCA distances than the handoff condition. Using Air MIDAS, the free flight operations demonstrate a similar pattern with the no handoff condition providing a larger PCA than the handoff condition. Using IPME however, the free flight condition provides no significant evidence that the no handoff condition possessed different PCA values than did the handoff conditions.

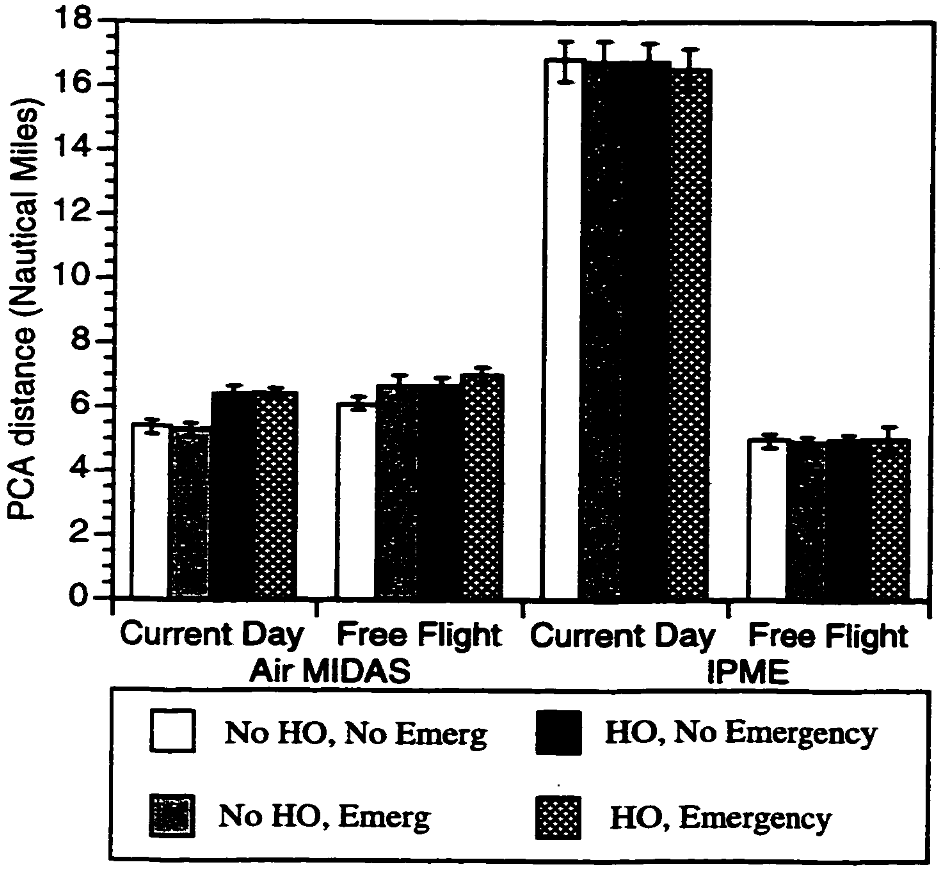

Figure 18. Point of Closest Approach (PCA) - Model (Air MIDAS or IPME) by Locus of Control (Current, Free Flight) by Handoff (No Handoff, Handoff) by Emergency (No Emergency, Emergency) Condition. No HO refers to the No Handoff and HO refers to the Handoff condition.

As indicated in Figure 18, the emergency condition appears to have an influence on model prediction in Air MIDAS' current day. This is a positive influence on the PCA distance with PCA distances being farther away in the emergency condition than in the non-emergency condition. IPME also possessed a slightly increased PCA distance when operating in an emergency condition although not significantly different. This provides some evidence that the software tools are performing in an emergent-style as the models are operating consistent with priorities of the tasks to be completed. It appears as though the human performance modeling software is not recognizing the difference between the emergency condition and the handoff condition, a non-emergency situation. An examination of the PCA means from both of the modeling software tools indicates that differences do exist in the model-generating component of the software tool. This difference exists even though the two software tools were programmed in a similar fashion.

Discussion

The purpose of this modeling effort was to examine the impact of transitioning from a current ATC operational environment to a free flight operational environment. A cross-comparison between Air MIDAS and IPME's predictions of system effects associated with the transition to free flight (and the increased use of automation) was also performed. Human interaction in complex systems performing in complex operating environments that have high consequences of failure requires the use of a safe system to examine the impact of adding requirements on the currently resource-limited human performer (Sheridan, 1997; Wickens, 1992). One such means of accomplishing this is through using human performance modeling tools.

Up until recently the use of human performance modeling tools have been task-oriented (Laughery & Corker, 1997). In order to develop means of dealing with the increasing complexities in the advancing operating environment, credence must be given to human constraints beyond simply the task structure or behavior and recognize the importance of cognitive aspects of human performance. Human performance modeling efforts have recently been examining this area. Collectively, First Principles modeling software tools have been proposed as an alternative to the more expensive human-in-the-loop procedures of testing new technology particularly at early stages in the design phase (Laughery & Corker, 1997). Early in the design phase is a critical stage for identifying variables that need human-in-the-loop examination. All modeling software tools that follow First Principles methodology are not the same however. Differences exist in many aspects of the imbedded nature of these modeling software tools that may be due to the developmental philosophy behind the software.

Procedural Rule Set Change: Locus of Control's Predicted Effects

It is apparent that irrespective of the modeling software tool used, the Locus of Control (LOC) was predicted to have a large effect on system-wide workload and the PCA of the aircraft in the NAS. This is consistent with the predictions from the first hypothesis that stated that simulated operator decision, time of simulated operator decision, and the simulated operator workload trace (Laudeman et al., 1998; Lozito et al., 1997; Wyndemere, 1996), would show a difference depending upon the LOC. The simulated operator decisions were anticipated to be different in each LOC because the nature and responsibilities of the operator are different with the different rule set. This difference in responsibility results in the simulated operator making different decisions and implementing different actions. The procedural sequence of tasks was different between the two LOCs. The results indicate that workload is increased in free flight as compared with current day operations. Shifting the tasks between the simulated operators does provide simulated evidence of supervisory control theory as the simulated operators actually had an increase in predicted workload. Sheridan's (1992) supervisory control theory predicts that the nature of the tasks of operators greatly impacts the subjective workload associated with the task. This simulation provides some support for this theory as the simulated operators possessed increases in workload given the change in their role.

The current modeling effort identified that the LOC change may have differing impacts on the operators. There was a consistent pattern of results between the LOC and the Operator Role between the two models. As indicated in the results, there are predicted increases in operator workload in specific segments of the operating environment while predicting workload savings to other segments of the operating environment. This has importance because there is a consistent prediction being made by both integrated human performance modeling tools. The location of the human operator is predicted to be subject to differential workload increases during the transition from current day, ATC control of the airspace to one of cockpit, or free flight, control. This effect is important because the operational areas within the NAS are in need of equal distribution of workload. Shifting the workload from the ground to the air possesses potential workload savings for the ground environment as predicted by both Air MIDAS and IPME while increasing the overall demands on the simulated flight-crew. This has importance because there is the prediction that different operators in the NAS system will be differentially affected by the procedural set of rules that accompany the move towards free flight (Wickens, et al, 1998). The effect of this role transfer is still currently unknown but there is much research planned to examine this effect prior to the acceptance of the LOC change. There are predictions made by Sheridan (1992) that this role transfer will involve the ground operators being placed to an increasing extent into a role of supervisor. This will involve monitoring the condition of many displays that indicate the status of the NAS and will increase the operation of the human operator in a fundamentally weak human performance role, that of passive monitor. The air-crew will be placed with increasing active-control responsibilities. This may lead to problems by increasing the operator demands beyond their human performance limits (Wickens, 1992). This provides evidence that the roles that free flight implementation will require of the human may be negative for human performance as there are many predicted attentional and behavioral effects that need observation prior to moving forward with such a rule set change.

There was a difference between the modeling tools' predictions of the point of closest approach (PCA). The first hypothesis stated that the modeling software tools would not produce differences in their predictions associated with the PCA. This did occur however. The Air MIDAS modeling software tool attempts to predict the most optimal solution to any of the performance characteristics that are involved in the human performance simulation model, even if this involves the simulation generating structures of the modeling software. It appears that the Air MIDAS software has scheduled the aircraft along the optimal solution for conflict avoidance thus resulting in the most efficient routing of the aircraft given its upcoming required deconflicting actions (Tyler et al., 1998). IPME on the other hand schedules tasks to occur on a task-by-task basis and therefore has scheduled the task of deconfliction to occur at the point when the conflict situation becomes apparent to the operator (Laughery & Corker, 1997). As a result, as soon as the conflict has become apparent to the ground controllers and a resolution is commenced, the aircraft perform a characteristic avoidance maneuver that is defined as being a ten-degree heading change. This ten-degree heading change is an optimal solution for conflict avoidance in the free flight situation where the look-ahead distances (the distances that the NAS operators are provided with the conflict information) between the aircraft are much reduced. When this previously optimal deconfliction process is compared with the current day rule, the efficiency of the action is questionable under free flight.

This modeling effort predicts that the move towards free flight will result in greater system-wide workload and Air MIDAS predicts that aircraft operating under free flight rules may have points of approach further apart than current day operations in the NAS. IPME predicts that the change towards free flight will result in greater system-wide workload while possessing closer PCA between aircraft in the NAS. This finding indicates that the anticipated benefits of free flight are not necessarily in the expected direction using the IPME modeling tool when the cockpit is provided the last level of alert. In fact, decentralizing the level of authority from the ground into the cockpit may cause undue workload while at the same time increasing the frequency with which aircraft come within separation standard violations, at least according to IPME's predictions. This is consistent with the predictions as outlined by Wickens et al. (1998)

and those predictions of automation's effect on human performance by Parasuraman (1997) and Endsley (1995a). An evaluation of the PCA findings predicted by each of the modeling software tools indicates that greater distances between aircraft will exist during ATC rules of separation as compared with free flight rules of separation. Wickens et al. (1998) indicates that free flight rules of operation have the potential of increasing the consequences of an airspace conflict. From an evaluation of the main LOC predicted differences, this modeling effort predicts that the adoption of such a LOC change possesses the potential of increasing the consequences of an airspace conflict. It is now necessary to evaluate the effect of such a rule set change using a variety of human-in-the-loop simulations to examine the real effects that the procedures will have on human performance and the NAS prior to their general acceptance into such a critical environment.

Identification of a Critical Variable: The Handoff Condition

Evaluating such significant system-wide changes, as is the case with the implementation of free flight rules, requires a cost-effective identification of critical variables for inclusion in human-in-the-loop examinations. Beyond the obvious differences that will exist using the different procedural and operational rule set identified above, two additional critical variables were identified as possessing potential human performance influences. The first variable is the handoff condition and the second is the emergency condition. Given concerns raised by RTCA, Inc. (1995) it was hypothesized in the second hypothesis that the occurrence of a handoff situation will cause increases in the simulated operator's workload according to each modeling software tool's prediction. Using the predictions provided by both modeling software tools, there is a suggestion that the handoff condition during a conflict resolution plays a role in increasing the workload of the operators in the NAS. This is consistent with predictions made by Wickens (1992) that dealing with multiple tasks that require the attention of a resource limited human operator will affect the operator's performance on the primary task. This has importance because the handoff condition is not the primary task. The primary task usually possesses some degree of time criticality. A handoff task is one that needs to be completed but does not need to be completed at a specific point in the operating environment, thus not being time critical. This means that regardless of the time-related pressure, there is a suggestion from both modeling software tools that workload is increased in a handoff over a no handoff situation. A consistent prediction was found between the handoff and the operator role interaction among both the Air MIDAS software and the IPME software prediction. It had been anticipated that the modeling software tools would not be different in their predictions of operator workload performance (IPME 1998; Tyler et al., 1998). The two modeling software tools predicted that the handoff event causes workload increases in the simulated operator. This is suggesting that the workload scheduling mechanisms of both modeling software tools are consistent. The reality of this predicted effect of multiple task performance needs further evaluation and validation with human-in-the-loop data.

Model output was compared along many dimensions in the current modeling effort. The finding that the handoff condition produces a significant effect on operator performance is important because it provides evidence that the human performance models are both operating consistently and in an ecologically valid manner (Kirlik & Bisantz, in press; Kirlik, 1995; Vicente, 1995). Modeling tools that do not accomplish this increase the degree to which the results may be questioned. For the PCA however, differences do exists between the models' predictions. The Air MIDAS model predicts a closer PCA during the no handoff condition than during the handoff condition. One possible explanation for this effect is that in the no handoff condition only one operator is controlling the airspace and this one operator will need to share resources between multiple aircraft to deal with the conflict situation. This indicates that a separation violation, although not triggered, is more likely during a no handoff condition than during a handoff condition in Air MIDAS because only one operator is controlling the sector and this operator possesses increased demands thus requires increased time to complete the tasks. This is characteristic of human performance when dealing with multiple tasks (Lehto, 1997; Wickens, 1992). A difference in workload but no difference in PCA was predicted by the IPME. The reason that the IPME software did not predict the same as the Air MIDAS software could be the result of the task-oriented nature of the scheduling mechanism within IPME. The Air MIDAS model which relies less on the task oriented nature of behavior and more on the characteristics of the human operator appears to indicate that the handoff condition does possess an impact on simulated operator behavior as reflected by the control input timing. This is consistent with findings from Corker and Pisanich (1995) who indicate that the Air MIDAS model validly predicts human performance in complex distributed aviation systems. Given that the Air MIDAS predictions have been previously validated, it is proposed that future human-in-the-loop evaluations include the variable associated with handoffs when evaluating the system change to free flight. This will provide the opportunity to explore the validity of the disparate model findings that exist between the PCA and the workload predictions made in the current study.

Identification of a Critical Variable: The Emergency Condition

The third hypothesis stated that the workload as well as the distance-related characteristics of the simulation would be greatly impacted by the occurrence of an emergency situation. It is interesting to observe that the emergency condition did not have the effect on the human performance model that was anticipated of causing greater performance differences than non-time critical tasks (Lehto, 1997). Using each of the modeling software tools, the emergency condition increased the mean system-wide workload over the no emergency condition but this increase was often less than the increase in the non-time critical task of dealing with a handoff. When a human acts in response to a time critical task, often there is an increase in workload that negatively affects performance (Lehto, 1997; Wickens, 1992). The model does not seem to place as much priority on the emergency situation expected from a human-in-the-loop simulation as there is not a predicted increase in workload in the current modeling effort. This occurs because the modeling software tool needs to complete a task that has been started regardless of priority. Priority levels become important when there are multiple tasks beginning at the same time. The emergency condition is a time-critical variable that human performance models as a whole need to better replicate. Caution needs to be taken when using the human performance modeling software tools for evaluation of time-critical variables such as the emergency variable in the current study. The results from this modeling effort appear to suggest limited benefit on overall workload measures of including such time-critical variables in human-in-the-loop empirical evaluations. This is obviously not the case in empirical evaluations of human behavior because when a time critical variable is included in a human-in the-loop evaluation, there are generally differences between the performance on the time critical and the non-time critical task (Lehto, 1997). For this reason, there needs to be further evaluation of time-critical tasks both by human performance models and in human-in-the-loop simulations. The differences of the time-critical task and the non time-critical tasks both have a significant influence on the model's prediction of operator performance. This provides some evidence that human workload will be significantly affected by any task that is requiring the attention of the operator irrespective of its importance.

The third hypothesis also stated that the models would provide evidence that the emergency condition would cause the aircraft to be closer to one another when the maneuver was made to avoid a conflict situation due to an increase in tasks required to take emergency-based actions. The PCA appeared to be differentially affected depending upon the modeling software tool's replication of an emergency. Given that the Air MIDAS software is based on determining the optimized solution to the conflict situation, it is apparent that tasks expected to heighten workload to a great extent do not produce the anticipated heightened workload but do influence the output of the PCA between the aircraft. Air MIDAS predictions of PCA are such that the occurrence of an emergency condition will cause a significant difference between the PCA distances between the no emergency and the emergency condition. This is a consistent finding with the human-in-the-loop research indicating that time pressure and stress influence the decision making of individuals (Lehto, 1997). By definition, an emergency condition is a condition exemplified by increased time pressure. Time pressure has been shown to cause poor human decision making and poor human performance on time related tasks. The IPME appears to schedule the emergency condition in a slightly different manner as evidenced by the current study's predictions. The results from IPME appear to suggest that the model is predicting no significant difference between the aircraft PCA regardless of whether the aircraft are reacting to a potential emergency condition. This finding is counter to Lehto (1997) and is likely occurring due to the scheduling algorithms that are contained within IPME. This is indicative that Air MIDAS is requiring less time than IPME to respond to the simulated emergency events which amounts to a greater distances (thus closer PCA) to complete the tasks required in conflict avoidance because the distance is determined by the immediate completion of the task.

Predicted Human Performance Interactions

Multiple Resource Theory (MRT) proposed by Wickens (1992) indicates that when dealing with multiple inputs, the human operator faces some limitations in processing the information in the operating environment. The results of the current study reveal that the simulated operators within the NAS will be differentially affected by the role that they perform in the system. The role will determine which operator resources will be active and that the change between active resources may be problematic for the human operator. The current evaluation indicates that multiple channels are being differentially affected depending upon the location of the specific operator and on the responsibilities that this operator possesses. These results do need to be validated with human-in-the-loop experimentation and if they are found to be correct, care needs to be taken when moving towards a system as the one being proposed for the NAS.

When looking at the interaction among the LOC and the emergency condition, system-wide workload and PCA distances increased when the simulated operators were performing under free flight rules as opposed to current day rules using the Air MIDAS software. The Air MIDAS software used in this modeling effort predicts that there is a benefit for system performance as measured by workload levels when dealing with an unforeseen event (emergency) under free flight as opposed to dealing with an unforeseen event during an emergency under current day rules of operations). This predicted simulation model finding is counter to the human-in-the-loop findings of Degani, et al., (1996) who found that changes in operator expectations lead to greater workload increases. This finding needs validation from human-in-the-loop simulation. The LOC by emergency interaction along the predicted human performance effects as represented by the PCA distances are indicative that there is a benefit for aircraft safety as the aircraft are further apart under free flight during an emergency than during a no emergency condition. This is because the priority of the emergency task is causing the actions of the Air MIDAS operator to schedule immediate completion of the task. This result was not consistent with the finding of the emergency's influence on workload using IPME. IPME predicts that there is little benefit for system performance as measured by workload levels when dealing with an unforeseen event (emergency) under free flight as opposed to dealing with an unforeseen event during an emergency under current day rules of operations. The PCA distance is also not significantly affected by the interaction of the LOC and the emergency condition. This IPME finding goes counter to the human-in-the-loop research that indicates that the time-pressured tasks will result in poor decision making and the decision that are made will be subject to increased time associated with making the decision (Lehto, 1997).

Model Scheduling Properties

It is apparent when examining the results that there are higher level interactions existent in Air MIDAS that do not exist when using the IPME software. The differences between the two models' output suggest a very important difference in the way the model structures or schedules behavior. Hybrid models like IPME appear to schedule tasks based on the task itself and on the task's interaction with the other tasks in the external simulated environment. The emergent-behavior style of model like Air MIDAS appears to reflect greater influence of performing multiple concurrent tasks that utilize shared resources because the emergent behavior model algorithm mediates the effect of multiple tasks on performance. This algorithm is a dynamic algorithm that feeds back into model future performance, thus affecting the human performance output. The dynamic algorithm in the Air MIDAS software validly replicates complex human behavior in advanced aviation systems (Corker & Pisanich, 1995b). Often, as was the case in the current evaluation, the operator was performing in a continuous loop activity such as visually monitoring. This requires the operator to continually examine the outside environment while also dealing with small deviations in the visual monitoring to attend to other tasks as identified by priorities in the external environment. The hybrid model actually was able to perform this similar behavior by scheduling a task to replicate the visually monitoring task represented in the emergent-behavior model. This visual monitoring task would then be interrupted by other tasks in the external environment. The result is a slightly different representation in task performance. The respective benefits of the two software approaches need to be further evaluated using human-in-the-loop studies.

An interesting and somewhat unexpected finding was discovered in the workload calculations of the current modeling tool cross-comparison. Upon examination of the workload results, it can be observed that the modeling tools appear to possess greatly divergent numbers with the Air MIDAS software tool providing smaller numbers than the IPME software tool. This result is occurring because the emergent models such as Air MIDAS are based on a large number of observations while the hybrid-style of modeling software like IPME are based on a much smaller number of workload observations. This difference in observation numbers causes the modeling software to be mathematically influenced to a differential extent. The Air MIDAS software uses a very large number of observations upon which to base the average workload value. IPME on the other hand utilizes only the workload values that are associated with the tasks that have been programmed into the model, a much smaller number than the number of observations within Air MIDAS. This means that the IPME model workload output is being greatly influenced by individual tasks. These differences exist due to the scheduling mechanisms within the respective modeling tool.

Model Generating Structure

It is important to realize that differences may exist in the model generating structure of the modeling tool. The difference in the PCA between the models is important because it is a direct result of the logical steps produced by the scenario generating structure. The emergent-behavior model Air MIDAS required a full scenario generating sketch of the actual airspace including latitude and longitude representations while the IPME utilized a X, Y coordinate system to represent the airspace. The task-oriented model provided an output that is consistent with the model performance associated with simple task completion over an emergent-behavior being elicited by a task in the operating environment. There is evidence that differences exist between the generating structures of the models as very small variations in procedural behavior produce significant operational changes as evidenced by the PCA data in the current model comparison. The precise cause of the difference needs further examination in other multiple model comparisons and requires validation with human-in-the-loop data. It is possible that the behavior elicited by the task-network model is more stringent with respect to definitions of simulation operations while the emergent-behavior models are less stringent with respect to the definitions of simulation operations. The task-oriented modeling software requires specific actions to be performed in response to a situation in the simulated operating environment (Laughery & Corker, 1997). This information should be evaluated with respect to human-in-the-loop simulations as this is a critical fact for establishing validity of human performance models as a complement for human-in-the-loop simulations.

A final difference between the models that could be having an effect on the human performance values as output from the models involves the overall amount of programming that is required in developing the model. The relative simplicity of the model generating structure may be associated with the greater performance effects as predicted by IPME. The more detailed the generating program, such as that represented by Air MIDAS, combined with a much larger interactive structure may result in more accurate measures of human performance. The model generating structural differences that exist between the models appears to be influential on the amount of workload that is experienced by the simulated operator. The Air MIDAS software predicts PCA significant differences at higher level interactions while in IPME there is no significant difference between the PCA distances in higher level interactions. This is an important characteristic because the workload that is experienced by the simulated operators is also different between the two models. Recalling that the Air MIDAS was less likely to predict differences between the predicted workload experienced by the simulated operator at higher level interactions. The IPME was more likely to predict significant differences in workload experienced by the simulated operator at higher level interactions. The PCA differences between the models are in an opposite direction. This provides some evidence that the PCA distances according to the model characteristics of the modeling software tool are accurately influencing the simulated workload.

For these reasons, the results from any human performance modeling software tool should not be used as a substitute for human-in-the-loop studies and should not be used for drawing firm conclusions from modeling tool output. The danger that exists with applying the results without correct validation and verification is that the model may not be using the same calculation methods for human performance responses as a result of the different empirical research that was used to create the human response algorithms. Additionally, each modeling software tool utilizes different processes to measure and quantify the results. Some of the modeling software tools use the emergent behavior to quantify results while others such as the hybrid model, utilize the task oriented structure upon which to measure results. This has been well exemplified in the current modeling effort. Both models were created from the same task list yet each revealed different human workload performance effects caused by the manipulations that were made. The human performance modeling tools should not be thought of as a substitute for human-in-the-loop performance, rather they should be thought of as a complement to the study of behavior that can be used early in the design phase to refine the overall study goal. A critical evaluation of the costs of human-in-the-loop simulation is required to improve the generalizability of the findings from the human-out-of-the-loop simulations.

Conclusion

Human performance modeling software tools are not yet at a point where they can be substituted for empirical experimentation. Often, such as early in the design process, all that is often possible is a computer model of human-system interaction, such as is the case for free flight. The early input into the design process outlines the beneficial aspects of the modeling tools. As the system under evaluation moves into the design phase, the human factors researcher will want to verify the findings from the human performance modeling tool with higher fidelity simulation with human operators, experimentation and prototyping. Human performance modeling simulation can be used to extend the findings of the limited experimentation associated with new technologies. The variables outlined in the current study should be further validated with human performance values. These human performance values should first be obtained using a high fidelity simulation environment. This human performance modeling effort has outlined some workload issues that that are recommended for incorporation into future high fidelity simulations. The current modeling effort has begun the process of model cross-comparisons in an attempt to better understand the abilities and constraints on computer simulations of human performance. This modeling effort has also opened the door for validation efforts with human-in-the-loop data. This modeling effort also provides the possibility of increasing the complexity of the IPME model in order to evaluate whether an increase in complexity may permit the hybrid models such as IPME to closer approximate the emergent models such as Air MIDAS. If this does exist, then perhaps the "emergent" nature of human performance may be representing a series of highly complex inter-related tasks. This increased understanding of the relationship between the emergent and the hybrid models' scheduling mechanisms that are contained within the existing human performance models may further augment the validity of the human performance model.

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Appendix A. Overview of current rules and free flight rules.

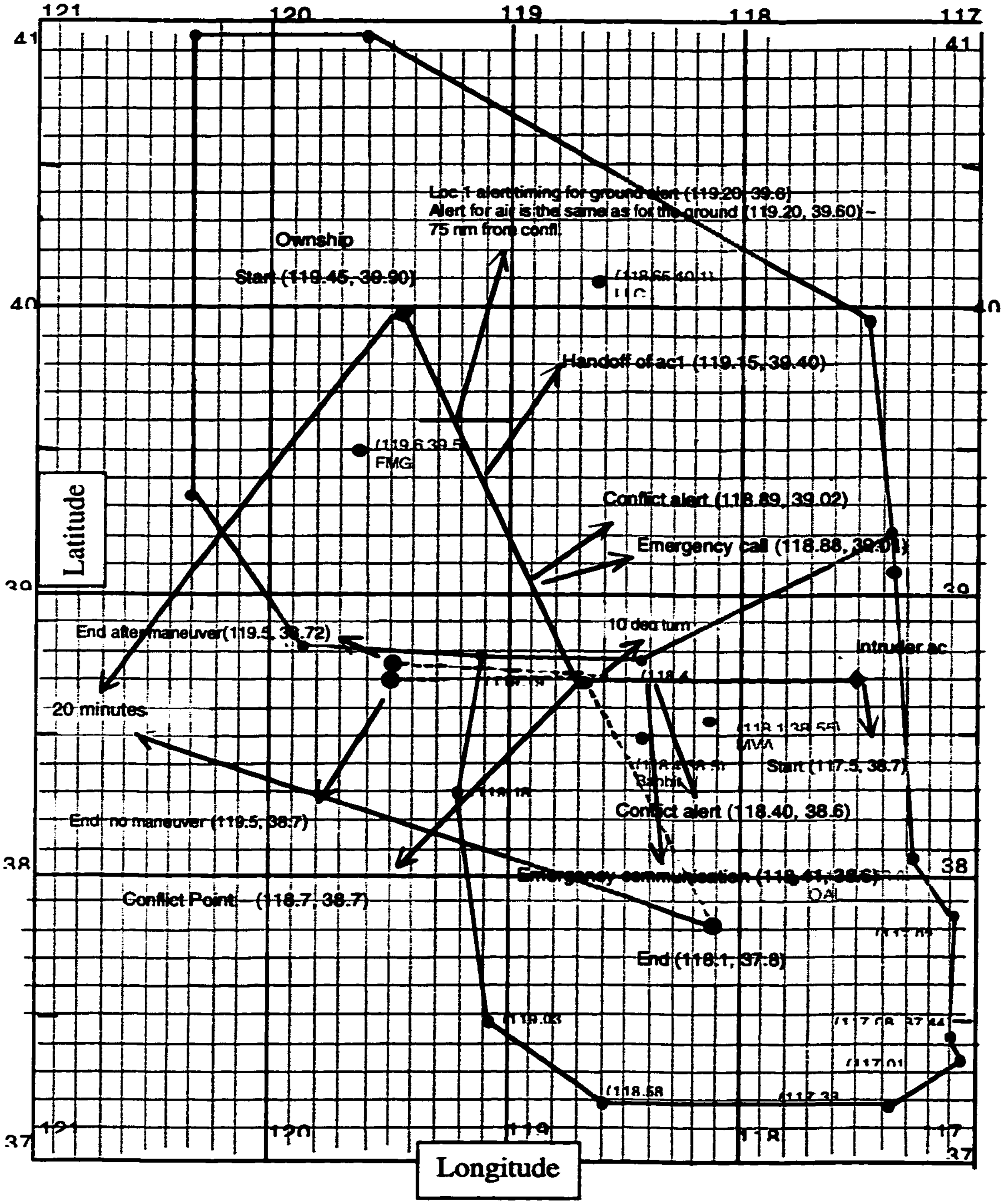
General Overview: Current Day Rules

Controllers will take the initiative to resolve conflicts between aircraft.
Pilots cannot take any action (other than emergency or TCAS RA) without a clearance from ATC.
Pilots can query controllers (e.g. potential conflicts, clearances received, etc.) and make requests based on information from their CDTI displays.
Controllers shall update the Host/DSR database when flight plans are changed.

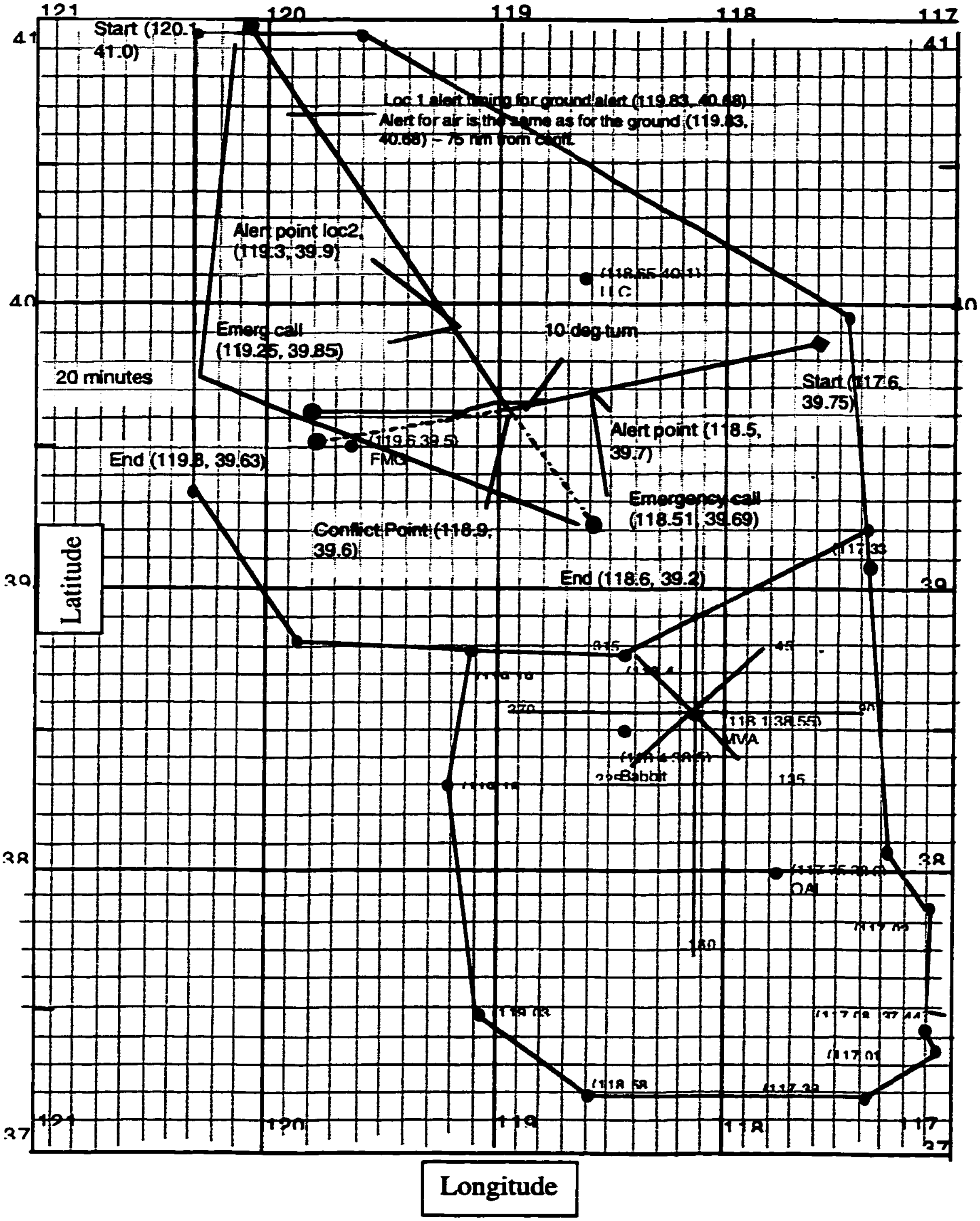
General Overview: Free Flight Rules

Flight crews are free to maneuver in any direction including vertically provided they first inform ATC.
Standard separation rules of 5 miles laterally or 1000/2000 ft. vertically shall be observed by ATC and flight crews.
Flight crews of aircraft in a conflict identified on the CDTI must communicate with each other over the air-to-air frequency. Specifically, the aircraft that should maneuver based on right-of-way is responsible for initializing the communications. If no communication can be established, ATC should be promptly informed so they can intervene (e.g. resolve the conflict; assist the pilots in agreeing on a resolution, etc).
Flight crews shall use specific right of way rules to resolve conflicting situations.
Flight crews can request ATC to intervene at any time.
ATC can assume control at any time he/she feels the situation is becoming unsafe.
Controllers shall update the Host/DSR database when flight plans are changed.
Controllers shall issue *Traffic Alerts* using prescribed phraseology to the aircraft involved in any red URET alert the controller feels is not a 'false alert'.
Controllers shall coordinate all red URET alerts they feel are not 'false alerts' on aircraft not under their control with the controlling sector using the prescribed phraseology.
Controllers receiving a coordinated *Traffic Alert* shall forward this to the subject aircraft unless that aircraft has already advised that a resolution is in progress.
Controllers shall have the prerogative to wait to issue a traffic alert until the subject aircraft is under his control if he feels it is safe to do so.
Controllers shall coordinate any aircraft action that will affect another controller's airspace.

Appendix B. Latitude and longitude positional information for no handoff condition.


121
120
119
118
117
41
40
39
38
37
Loc 1 alert timing for ground alert (119.20, 39.6)
Alert for air is the same as for the ground (119.20, 39.60) ~
75 nm from confl
Ownship
Start (119.45, 39.90)
(118.65 40.1)
Handoff of ac1 (119.15, 39.40)
(119.6 39.5
FMG
Latitude
Conflict alert (118.89, 39.02)
Emergency call (118.88, 39.01)
End after maneuver(119.5, 38.72)
10 deg turn
Intruder ac
20 minutes
(118.4
(118.1 38.55)
MVA
Rabbit
Start (117.5, 38.7)
End no maneuver (119.5, 38.7)
Conflict alert (118.40, 38.6)
Emergency communication (118.41, 38.6)
OAL
Conflict Point (118.7, 38.7)
End (118.1, 37.8)
(119.03
(117.08 37.44
(117.01
(118.58
(117.38
Longitude

Appendix C. Latitude and Longitude positional information for handoff condition.


121
120
119
118
117
41
40
39
38
37
Start (120.1, 41.0)
Loc 1 alert timing for ground alert (119.83, 40.68)
Alert for air is the same as for the ground (119.83, 40.68) – 75 nm from conft.
Alert point loc2, (119.3, 39.9)
(118.65 40.1)
LLC
Emerg call (119.25, 39.85)
10 deg turn
20 minutes
Start (117.6, 39.75)
(119.6 39.5)
FMG
End (119.8, 39.63)
Alert point (118.5, 39.7)
Emergency call (118.51, 39.69)
Conflict Point (118.9, 39.6)
(117.33
End (118.6, 39.2)
315
45
270
90
(118.1 38.55)
MVA
Babbit
225
135
180
(117.75 38.0)
OAL
(119.03
(118.58
(117.39
(117.01
Latitude
Longitude

Appendix D. System task performance (LOC1).

Standard Operations Scenario: Pilots moniotr CDTI controlers intervene with URET

	V	A	C	P	t	SD	Min	Max		V	A	C	P	t	SD	Min	Max		V	A	C	P	t	SD	Min	Max		V	A	C	P	t
ATC1									ATC 2									FLTGRW 1									FLGHTCRW 2					
Monitor A/V	1	1	1	0	cont.				Monitor A/V	1	1	1	0	cont.				Monitor A/V	1	1	1	0	cont.				Monitor A/V	1	1	1	0	cont.
	dist to boundry <= 6 miles																															
Initiate hndoff	2	2	2	2.2					receive hdnoff	2	4.3	2	2.2	15	3	7	35															
									acknowledge	1	4.3	6.8	2.2	2	1	1	4															
receive ack	2	4.3	2	2.2	2	1																									
transmit info	4	1	5.3	2.2	16	6			receive info	1	4.9	5.3	0	21	10	5	50															
note hndoff	4	0	4.6	4.6	10	3																										
call Ac1	5	1	6.8	4.6	15	5												receive call	0	4.9	3.7	2.2	25	10								
																		ack hndoff	0	4.9	3.7	2.2	2	1	1	4						
																		atc1														
achn AC1 (frq)	0	4.9	3.7	2.2	2	1												achn frq	0	4.9	3.7	2.2	2	1	1	4						
																		ATC2 frq dial	5	0	5.3	5.8	5	2	2	10						
																		wait for call	0	1	1	0	cont.									
									dist from boundry <= 6 miles																							
									init contct Ac1	5	1	6.8	4.6	5	1	1	10	ack ATC2	0	4.9	3.7	2.2	2	1	1	4						
									tansmit clr	0	4.9	6.8	2.2	15	3	3	30	ack clr ATC 2	0	4.9	3.7	2.2	5	2	2	10						
									receive ack	0	4.9	3.7	2.2	2	1	1	4															
blank	blank								blank	blank								blank					blank				blank					
conflict tasks	conflict tasks								conflict tasks	conflict tasks								conflict tasks					conflict tasks				conflict tasks					
mntr a/v	1	1	1	0	cont.				mntr a/v	1	1	1	0	cont.				mntr a/v	1	1	1	0	cont.				mntr a/v	1	1	1	0	cont.
URET ALERT	6	5.9	7	0	2	1	1	4	URET ALERT	6	5.9	7	0	2	1	1	4	mntr a/v	1	1	1	0	cont.				mntr a/v	1	1	1	0	cont.
Observe CRT	1	1	1	0	continous				Observe CRT	1	1	1	0	continous																		
Initiate Within-sector communication	7	1	5	4	5	2	2	9	Initiate Within-sector communication	7	1	5	4	4.5	2	2	9															
Receive Ack	0	4	7	2	6	3	3	14	Receive Ack	0	4	7	2	6	3	3	14															
comm. intent	0	1	7	1	10	7	5	22	comm. intent	0	1	7	1	10	7	5	22															
Receive Ack	0	4	7	2	6	3	3	14	Receive Ack	0	4	7	2	6	3	3	14															
									trnst alrt AC1	4	1	5.3	2.2	16	6	15	30	receive clr	0	4.9	3.7	2.2	25	10	10	50						
																		cck CDTI	5.4	0	6.8	1	30	10	10	60						
																		ach alrt	1	4.3	6.8	2.2	2	1	1	4						
									notes AC1 ach	4	0	4.6	4.6	10	3	5	25	trnsmt ack	1	4.3	6.8	2.2	2	1	1	4						
									trnsmt clr AC2	1	4.3	6.8	2.2	2	1	1	4															
																											receive clr	0	4.9	3.7	2.2	25
																											chck CDTI	5.4	0	6.8	1	30
																											trnsmt ach	1	4.3	6.8	2.2	2
									receive ack	0	4.9	3.7	2.2	2	1	1	4															
									ntote ach	4	0	4.6	4.6	10	3	5	25															
																		flght mngt rch	5	0	1.2	2.2	3	1	1	6						
																		fms visscan	5.9	0	5.9	1	5	2	2	10	flght mngt rch	5	0	1.2	2.2	3
																		button push	4	0	1.2	2.2	2	1	1	4	fms visscan	5.9	0	5.9	1	5
																		slct alt	4	0	6.8	5.8	4	2	2	8	button push	4	0	1.2	2.2	2
																		button push	4	0	1.2	2.2	2	1	1	4	slct alt	4	0	6.8	5.8	4
																		slct spd	4	0	6.8	5.8	4	2	2	8	button push	4	0	1.2	2.2	2
																		button psh	4	0	1.2	2.2	2	1	1	4	slct spd	4	0	6.8	5.8	4
																		key wypt	4	0	5.8	6.5	40	20	20	60	button psh	4	0	1.2	2.2	2
																											key wypt	4	0	5.8	6.5	40
																		if pca <= 6 mi									if pca <= 6 mi					
																		cdti alrt	6	5.9	7	0	2	1	1	4	cdti alrt	6	5.9	7	0	2
																		adjsut params	4	0	6.8	5.8	4	2	2	8	adjsut params	4	0	6.8	5.8	4
																		pwr	4	0	6.8	5.8	4	2	2	8	pwr	4	0	6.8	5.8	4
																		mcp	4	0	6.8	5.8	4	2	2	8	mcp	4	0	6.8	5.8	4
																		monitor	4	0	6.8	5.8	4	2	2	8	monitor	4	0	6.8	5.8	4
																		vis scan inst	5.4	0	6.8	1	30	10	10	55	vis scan inst	5.4	0	6.8	1	30
																		confirm hdng	7	0	6.8	1	5	3	3	10	confirm hdng	7	0	6.8	1	5
																		confm alt	7	0	6.8	1	5	3	3	10	confm alt	7	0	6.8	1	5
																		confrm spd	7	0	6.8	1	5	3	3	10	confrm spd	7	0	6.8	1	5
									verfify AC act	7	0	6.8	1	15	3																	

Appendix E. System Task performance (LOC2).

Free Flight Operations Scenario: Pilots monitor CDTI and initiate maneuvers controllers monitor with URET

	V	A	C	P	t	SD	(M/M)		V	A	C	P	t	SD		V	A	C	P	t	SD	(M/M)		V	A	C	P	t	SD	(M/M)
ATC1								ATC2							FLTCRW1								FLIGHTCRW2							
Monitor A/V	1	1	1	0 cont.				Monitor	1	1	1	0 cont.			Monitor	1	1	1	0 cont.				Monitor	1	1	1	0 cont.			
	if dist to boundry> 3 miles cont.																													
	if dist to boundry <3 miles initiate handoff																													
Initiate hndoff	2	2	2	2.2				receive h	2	4.3	2	2.2	15	3																
								acknowle	1	4.3	6.8	2.2	2	1																
receive ack	2	4.3	2	2.2	2	1																								
transmit info	4	1	5.3	2.2	16	6		receive ir	1	4.9	5.3	0	21	10																
note hndoff	4	0	4.6	4.6	10	3																								
call Ac1	5	1	6.8	4.6	15	5									receive cl	0	4.9	3.7	2.2	25	10									
															ack hnd	0	4.9	3.7	2.2	2	1									
															ack frq	0	4.9	3.7	2.2	2	1									
achn AC1 (frq)	0	4.9	3.7	2.2	2	1																								
															ATC2 fr	5	0	5.3	5.8	5	2									
															wait for c	0	1	1	0 cont.											
								dist from boundry <= 5 miles																						
								init cont	5	1	6.8	4.6	5	1	ack ATC	0	4.9	3.7	2.2	2	1									
								transmit c	0	4.9	6.8	2.2	15	3	ack clr A	0	4.9	3.7	2.2	5	2									
								receive cl	0	4.9	3.7	2.2	2	1																

blank blank blank blank blank blank blank

conflict tasks conflict tasks conflic conflict tasks conflict tasks conflict tasks conflict tasks

mntr a/v	1	1	1	0 cont.				mntr a/v	1	1	1	0 cont.			
mntr a/v	1	1	1	0 cont.				mntr a/v	1	1	1	0 cont.			
receive alert zone CDTI								receive alert zone CDTI							
look at H	6	3	6	0	5	2	(2/10)	look at H	6	3	6	0	5	2	(2/10)
identify	6	0	6	0	10	3	(5/25)	identify	6	0	6	0	10	3	(5/25)
discuss c	4	5	6	2	30	10	(10/60)	discuss c	4	5	6	2	30	10	(10/60)
comm tc	0	4.9	3.7	2.2	10	3	(5/25)	comm tc	0	4.9	3.7	2.2	10	3	(5/25)
confirm c	6	3	4	0	15	5	(15/30)	confirm c	6	3	4	0	15	5	(15/30)
initiate r	4	0	6.8	5.8	20	8	(15/30)	initiate r	4	0	6.8	5.8	20	8	(15/30)
conclude	4	0	6.8	5.8	20	8	(15/30)	conclude	4	0	6.8	5.8	20	8	(15/30)
monitor	4	5	6	2	30	10	(8/40)	monitor	4	5	6	2	30	10	(8/40)
decide								decide							
rtrn-to-	4	5	6	2	10	3	(5/25)	rtrn-to-	4	5	6	2	10	3	(5/25)
discuss	4	5	6	2	20	10	(10/60)	discuss	4	5	6	2	20	10	(10/60)
initiate								initiate							
rtrn-to-	4	0	6.8	5.8	20	8	(15/30)	rtrn-to-	4	0	6.8	5.8	20	8	(15/30)
conclude	4	0	6.8	5.8	20	8	(15/30)	conclude	4	0	6.8	5.8	20	8	(15/30)

mntr a/v	1	1	1	0 cont.			mntr a/v	1	1	1	0 cont.		
URET ALERT	6	5.9	7	0	2	1	URET AL	6	5.9	7	0	2	1
ack alert	1	4.3	6.8	2.2	2	1	ack alert	1	4.3	6.8	2.2	2	1
fixate	7	1	4.6	1	1	1	fixate	7	1	4.6	1	1	1
cognate	1	1	6.8	0	8	2	cognate	1	1	6.8	0	8	2
memory	0	0	5.3	0	1	1	memory	0	0	5.3	0	1	1
note alrt	4	0	4.6	4.5	10	3	note alrt	4	0	4.6	4.6	10	3
trn off	4	0	1	4.6	2	1	trn off	4	0	1	4.6	2	1
mntr a/v	4	1	4	0 cont.			mntr a/v	4	1	4	0 cont.		
post-alrt													

Emergency Alert Emergency Alert Emergency Alert Emerge Emergency Alert Emer Emerge Emergency Alert Emerge Emerge Emergency Alert Emergency Alert

Receive Emerg.	6.8	4.3	6.8	2.2	5	2	(3/10)
Ack AC descent	6.8	4.3	4.2	2.2	2	1	(1/4)
broadcast call	6.8	4.3	4.2	2.2	2	1	(2/6)
call specific ac for req'd ma	6.8	4.3	6.8	2.2	5	2	(3/10)
call specific ac for req'd ma	6.8	4.3	6.8	2.2	5	2	(3/10)
mntr a/v	4	0	1	4.6	2	1	

AC 3

Make a turbulence emergency call immediate descent from FL 380 to FL330 or less

Call	0	4.9	7	2.2	2	1	(1/4)
receive cl	0	4.9	3.7	2.2	25	10	
initiate r	4	0	6.8	5.8	20	8	(15/30)
conclude	4	0	6.8	5.8	20	8	(15/30)

Appendix F. Modified McCracken and Aldrich scale values.

Scale	Scale Value	Descriptor
Visual	0.0	No visual activity
	1.0	Visually register-detect (detect occurrence of image)
	3.7	Visually Discriminate (detect visual difference)
	4.0	Visually Inspect – check (discrete inspection-static condition)
	5.0	Visually Locate – align (selective orientation)
	5.4	Visually Track – Follow (maintain orientation)
	5.9	Visually read (symbol)
	7.0	Visually Scan/Search/Monitor (continuous serial inspection, multiple conditions)
Cognitive	0.0	No Cognitive Activity
	1.0	Automatic (simple association)
	1.2	Alternative Selection
	3.7	Sign/Signal Recognition
	4.6	Evaluation Judgement (consider single aspect)
	5.3	Encoding Decoding Recall
	6.8	Evaluation Judgement (consider several aspects)
	7.0	Estimation, Calculation, Conversion
Auditory	0.0	No Auditory Activity
	1.0	Detect Register Sound
	2.0	Orient to Sound (general orientation – attention)
	4.2	Orient to Sound (selective orientation - attention
	4.3	Verify Auditory Feedback (detect occurrence of anticipated sound)
	4.9	Interpret Semantic Content
	6.6	Discriminate Sound Characteristics (detect auditory differences)
	7.0	Interpret sound patterns (pulse rates, etc)
Psychomotor	0.0	No Psychomotor Activity
	1.0	Speech
	2.2	Discriminate Actuation (button, toggle trigger)
	2.6	Continuous Adjustment (Flight control, sensor control)
	4.6	Manipulative
	5.8	Discrete Adjustment (rotary vertical, thumb wheel, lever position)
	6.5	Symbolic Production (writing)
	7.0	Serial Discrete Manipulation (keyboard entries)