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INFORMATION REQUIREMENTS FOR TRAFFIC AWARENESS IN A FREE-FLIGHT ENVIRONMENT: AN APPLICATION OF THE FAIT ANALYSIS

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16. Abstract

The goals of the current research were (1) to identify the information necessary for the pilot of the air carrier to maintain "traffic awareness," and (2) to apply and evaluate the utility of a cognitive task analysis called the Function Allocation Issues and Tradeoffs (FAIT) analysis (Riley, 1993) in order to assess a system that included a free-flight traffic environment, a pilot, and a Cockpit Display of Traffic Information (CDTI). One hundred information requirements were identified. The FAIT analysis indicated the following characteristics of the system are highly influential in a free-flight traffic environment: weather, general piloting skills, time of day, terrain, ownship state (e.g., altitude, attitude, speed), level of pilot mental workload, and perceived time pressure. Highly influential characteristics are important because they affect many other characteristics of the system. In using the FAIT analysis, characteristics are categorized as sensitive if they are affected *by* many other characteristics (i.e., they are vulnerable). Results from the FAIT analysis suggested that the following characteristics were very sensitive: type of action chosen by the pilot, level of pilot mental workload, appropriateness of planned action, ownship state, level of air traffic managers' mental workload, accuracy of current machine model, and level of confidence in planned action. Furthermore, the FAIT analysis allowed an identification of potential tradeoffs in the system. Finally, the results indicated that, when compared with operator-driven system design issues, automation issues, and miscellaneous issues, training is the most important issue to address in a free-flight traffic environment.This paper addresses situation awareness (SA) as it relates to surveillance activities in commercial air carriers. The concept of SA and relevant literature are reviewed and critiqued.

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TABLE OF CONTENTS

INFORMATION REQUIREMENTS FOR TRAFFIC AWARENESS IN A FREE-FLIGHT ENVIRONMENT: AN APPLICATION OF THE FAIT ANALYSIS

INTRODUCTION

The present research was undertaken to examine human factors issues associated with National Airspace System (NAS) modernization. The first phase of this research reviews the concept of situation awareness (SA) as it relates to pilot surveillance activities and is presented in a separate document (cf., Uhlarik & Comerford, 2002). The second phase of this research, presented in the current paper, identifies and classifies information requirements for pilot surveillance functions in the air carrier. Such informa?tion will be helpful in the process of designing new technologies for pilots in the future NAS.

1.0 A REVIEW OF RELATED RESEARCH

Williams and Joseph (1998) conducted a study examining the manner in which pilots mentally organize flight-related information. Their goal was to provide a foundation for the design of future data-link interfaces for general aviation (GA) pilots. They began by examining the functional architecture of the Operational and Supportability Implementation System (OASIS). This system will modernize existing Automated Flight Service Station (AFSS) equipment and provide GA pilots with important weather and flight planning information. Examination of the system's architecture identified 48 pieces of data that a GA aircraft could receive from and send to AFSS via data link. Williams and Joseph presented GA pilots with the list of 48 items and asked them to rate each in terms of its importance in performing surveillance, communication, and navigation functions. For the purposes of the present paper, Williams and Joseph's most relevant findings are represented in Figure 1.

Figure 1 illustrates the 26 pieces of information that GA pilots identified as being most important in performing surveillance activities, and it also represents pilots' perceived relations among these items. Specifically, the number of lines that connect two boxes is an indication of the perceived relation between the information within those boxes. For example, the perceived relation between "Rerouting" and "Traffic conflicts" is relatively

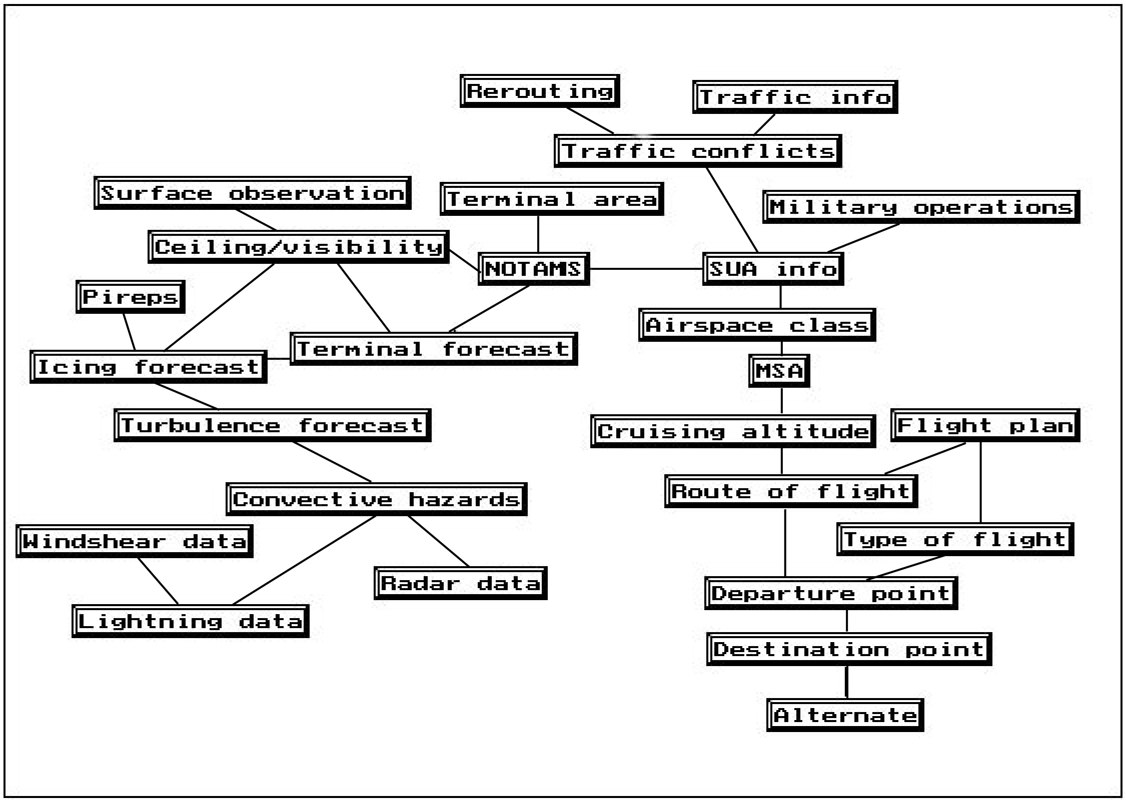

Figure 1. The typical conceptual network of data that is important in performing surveillance functions (from Williams and Joseph, 1998).

strong, because the nodes are connected directly by only one line. The relation between "Rerouting" and "Cruising altitude" is perceived as relatively weaker, as these nodes are connected only indirectly through four other nodes.

Although Williams and Joseph's study was limited to GA, the items identified as important to surveillance functions appear general enough that they may also be relevant to the design of technologies for transport air carriers. Note however, that the goal of the present study is not limited to information that can be obtained via data link. Neverthless, the findings of Williams and Joseph (1998) can be combined with the findings presented in the following pages.

Endsley, Farley, Jones, Midkiff, and Hansman (1998) conducted a study that also is relevant to the present research. They sought to identify the information requirements for commercial airline piloting. To identify these requirements, Endsley et al. examined job and task analyses that were performed in the past and conducted interviews with active airline pilots. There were three outcomes of their study: a goal hierarchy, a goal-directed task analysis, and a list of information requirements. The *goal hierarchy* identifies a pilot's "basic goal" as "Get aircraft from origin to destination safely, legally, with satisfactory levels of comfort and service to passengers, on schedule, and in an efficient manner." Four sub-goals were identified as being important in achieving the basic goal: "Select best path to destination," "Execute desired flight path safely, efficiently, and ride with comfort," "Manage resources effectively," and "Satisfy the customer." For each of the four goals, the necessary general tasks were identified, and for each general task, the necessary sub-tasks were identified. For example, the general task, "Assess flight plan" appears under the goal "Select best path to destination," and the sub-task "Push back from gate" appears under the general task "Assess flight plan." To perform the *goal-directed task analysis*, Endsley et al. used the goal hierarchy as a template and inserted the pilot information requirements under the appropriate headings. To produce the final *list of information requirements*, the goal-directed task analysis was used to extract information requirements that were common across goals, and this list was divided into several categories (e.g., aircraft state, airports, traffic).

The aim of the present research may appear redundant with the work of Endsley et al. (1998), in the sense that the questions posed in the present research can be answered by simply examining the relevant categories of information requirements identified by Endsley et al. In fact, several of the categories are directly relevant to the present research. For example, the list of information requirements contains categories such as "Traffic," "Terrain/obstacles," and "Weather." However, there are at least two limitations of Endsley's work that do not apply to the present research. First, their analysis performed by Endsley et al. was intended to be "as technology-free as possible" (p. 4). While a technology-free analysis is desirable for purposes of generalization, it may be unrealistic in the context of a technology-laden environment like the cockpit (and the free-flight environment, for that matter). Second, Endsley et al. purposefully ignored information that is static. For example, they did not include information related to procedures or rules. The present research does not attempt to make a distinction between static and dynamic information, insofar as this distinction can become quite unclear.

The problem with the static/dynamic distinction is exemplified by the rationale that Endsley et al. marshaled in their argument against including static information. Specifically, Endsley et al. implied that a rule, by its very nature, is static. However, rules often have dynamic information embedded within them (e.g., "If I'm flying above X feet, I may fly at my cruise speed of Y knots. However, if I'm flying below X feet, I must fly at Z knots"). In other words, it can be argued that rules are dynamic in the sense that the appropriate rule changes, depending on the surrounding (dynamic) circumstances.

An even more important reason for ignoring the distinction between static and dynamic information is related to the two primary goals for identifying information requirements: (1) the requirements might be used as a tool in developing a training program, and/or (2) they may be used as a tool in the development/enhancement of a user interface. For both of these applications, static information is just as important as dynamic information. One certainly would not want to develop a training program that ignores static information (e.g., rules), nor would one want engineers developing a piece of technology that fails to present the pilot with static information (e.g., a navigation tool that fails to present information regarding the location of unchanging fixes).

2.1 Summary of Related Research

The goal of the present paper is to identify and classify information requirements for pilot surveillance activities in the air carrier. The previously summarized research projects do not fully satisfy this goal. Although the research performed by Williams and Joseph is relevant, they examined only information that might be obtained via data link and concentrated on GA. Further, the research performed by Endsley et al. (1998) was limited in the sense that technology was not considered, and only dynamic aspects of the task were considered.

3.0 THE CURRENT RESEARCH: BACKGROUND INFORMATION

3.1 The Goal of the Current Research

The research performed by Endsley et al. (1998) demonstrates how complex and detailed a task analysis of all surveillance activities would be. The research described below is restricted to an analysis of the pilot's task of monitoring traffic during the cruise segment of flight. It is further limited to a free-flight environment, which has been proposed as the operational concept for the future NAS (RTCA, 1995). Therefore, the goal of the present research is to identify the information required for the air carrier pilot to achieve "traffic awareness" in the free-flight environment.

Traffic awareness is one component of the more general construct of situation awareness. As discussed in a separate document (Uhlarik & Comerford, 2002), there are many definitions of situation awareness. According to Wickens (1995), *situation awareness* is the "continuous extraction of environmental information about a system or environment, the integration of this information with previous knowledge to form a coherent mental picture, and the use of that picture in directing further perception, anticipating, and responding to future events" (p. 1). Although research has been conducted on several components of SA that are related to traffic awareness (e.g., environment, spatial, temporal, and navigation awareness), research on traffic awareness has been sparse. As a result, no formal definition of traffic awareness exists. The following definition of traffic awareness is used for the present research: *Traffic awareness* is having knowledge of the information necessary to obtain and maintain self-separation in the free-flight environment, where successful self-separation is defined as keeping ownship separated from other aircraft by 5 miles horizontally or 1,000 feet vertically.

While the pilot in the free-flight environment will obtain traffic information from several sources (e.g., out-the-window information, radio communications), the primary source of information presumably will be the Cockpit Display of Traffic Information (CDTI). Generally speaking, a CDTI is a cockpit display that provides the pilot with traffic information (e.g., ownship position, the position of other aircraft).[1] Because the CDTI will be the pilot's primary source of traffic information, identifying the information required for traffic awareness will be helpful in the design and certification of a CDTI for the free-flight environment.

The Function Allocation Issues and Tradeoffs (FAIT) analysis (cf., Riley, 1993) was chosen to identify the relevant information requirements. In general terms, FAIT analysis is a systematic procedure for identifying human factors issues in human-machine systems. The FAIT analysis was chosen because it appears to have great potential, and it provides substantially more information than a traditional task analysis. Among other things, the FAIT analysis (1) assists in identifying information requirements, (2) yields numerical values that represent the relative influence and the relative sensitivity of important aspects within the system, and (3) allows for the examination of tradeoffs in a human-machine system (e.g., when aspect X of the system reaches a desirable state, aspect Y consequently may reach an undesirable state). In addition, the FAIT analysis places equal emphasis on the human and machine components of the system, thereby, allowing the analyst to include purely psychological constructs (e.g., mental workload) of the human system component.

Despite its potential utility, the FAIT analysis has been used infrequently, and most published studies that utilize it have been conducted by its developer (i.e., Riley, 1989; Riley, 1992; Riley, Lyall, & Wiener, 1993). Therefore, in addition to identifying information requirements, the present research also provides a vehicle for evaluating the utility of the FAIT analysis. Specifically, to assess the utility of the FAIT analysis, the information requirements obtained via the FAIT analysis are compared with the information requirements identified by Endsley et al. (1998).

3.2 A Definition of the Human-Machine System

The FAIT analysis was developed with the assumption that it would be used for the analysis of complex human-machine systems (Riley, 1993). Toward this end, a necessary first step is to identify components of the human-machine system before the FAIT analysis is applied. For example, because complex human-machine systems generally include at least some level of automation, the analysis requires the researcher to determine the amount of control the machine possesses, and the following components must be identified: the human, the environment, and the machine. Obviously, the human component of the system to be analyzed in the current research is the pilot (although co-pilots, pilots of other aircraft, and air traffic controllers are ignored at this stage, they are taken into account later in the analysis). The environment for the human-machine system is identified as a modernized NAS, and therefore, the current research assumes that aircraft are equipped with Automatic Dependent Surveillance-Broadcast (ADS-B), which will allow aircraft to transmit and receive three-dimensional position information via data link. With such informa-

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[1] (A more detailed description of a particular example of a CDTI is provided later in this document.)

tion, the pilot may be responsible for self-separation in most instances, but the air traffic manager (ATM) will monitor traffic and control by exception. In other words, the pilot will perform tasks necessary for self-separation, and the ATM will intervene only in cases where alert zones overlap. For the current purposes, an alert zone is defined as a spherical area that surrounds an aircraft by five nautical miles on the horizontal dimension and 1,000 feet on the vertical dimension. However, if technology permits, these alert zones may be smaller. A final assumption was that the pilot would access the ADS-B information using a CDTI, which would be integrated into the current aircraft avionics suite. The CDTI was identified as the machine component of the system for the application of the FAIT analysis.

3.3 NASA-AMES CDTI

Because the FAIT analysis is intended for use in the early stages of the design process (Riley, 1993), a search was conducted for a candidate CDTI sill in the early stages of design. In fact, researchers at National Aeronautics and Space Association are currently examining design *concepts* rather than a specific display format or configuration of their prototype CDTI. The configuration and capabilities of the NASA-AMES CDTI varies considerably (e.g., Cashion,Mackintosh, McGann, & Lozito 1997; Johnson et al., 1997; Mackintosh et al., 1998), and the display used in the current analysis consists of a somewhat arbitrary collection of NASA display concepts. A brief description of this display appears below, but Appendix A provides a more thorough description of the CDTI.

Figure 2 presents a schematic of the NASA-AMES CDTI, which allows the pilot to view ownship position (depicted as a white chevron in the lower center portion of

Figure 2. The version of NASA's CDTI that was used in the current analysis.

Figure 2) in relation to other aircraft. In addition, altitude of other aircraft can be assessed in relation to ownship (i.e., other aircraft are color-coded according to altitude and their datatags display altitude numerically).

Using the toolbar at the bottom of the display, the pilot can configure the CDTI with there viewing options: (1) altitude can be displayed in absolute or relative terms, (2) datatags can be viewed or hidden, and (3) the predicted routes of aircraft can be viewed or hidden. In addition, when the appropriate option is chosen, the pilot can: (1) request that datatags be rearranged for optimum viewing, (2) change the amount of time the predictor lines represent, and (3) view the predictor lines in one of two formats. Finally, the Route Assessment Tool (RAT) allows the pilot to assess and accept (if so desired) changes in altitude, vertical speed, and heading. Therefore, a pilot who is considering changes (e.g., in altitude) is allowed to determine if an alert zone contact is likely before the changes are initiated.

4.0 A STEP-BY-STEP DESCRIPTION OF THE FAIT ANALYSIS

This summrizes of the current findings and, in the context of the current findings, presents a brief overview of the FAIT analysis procedures. A complete description of the analysis appears in the *Function Allocation Issues and Tradeoffs: User's Manual* (Riley, 1993). The FAIT analysis is divided into six major steps for ease of understanding.

4.1 Step 1: Develop a Model of Information Flow

The goal in the first step is to determine the model of information flow within the system. There are three tasks to be completed in determining the appropriate model. The first task is to identify the machine's level of autonomy. The FAIT user's manual provides a description of 12 levels of autonomy (cf., Riley, 1993, p. 6-8). The highest level represents a machine with complete autonomy (i.e., the machine performs control actions without informing or interacting with the operator), and the lowest level represents a machine with no autonomy. Utilizing complex algorithms (cf., Johnson et al., 1997), the NASA-AMES CDTI attempts to identify other aircraft that are likely to have alert zone contact with ownship, and therefore, the current analysis placed the NASA CDTI at the "Simple aid" level of autonomy. This classification fits nicely with Riley's (1993) example of a target recognizer that simply attempts to categorize radar returns as belonging to targets, and as such was classified as a "Simple aid."

The second task in Step 1 is to identify the machine's level of intelligence. Like the first task, the researcher is to choose the machine's level of intelligence from a list of seven levels (cf., Riley, 1993, p. 8-9). The highest level represents a machine with a high degree of "intelligence" (i.e., the machine has information regarding the operator's physical state and intent and therefore can predict the operator's behavior), and the lowest level represents a machine with virtually no intelligence (i.e., it presents only raw data).

Within this category, a machine viewed as "Personalized" is one that can be configured according to the operator's preferences. Therefore, because some aspects of the NASA CDTI can be manipulated in accordance with the pilot's preferences (e.g., datatags may be shown or hidden, predictors may be shown or hidden, the length of the predictors may be varied according to taste), the current analysis placed the NASA CDTI in the "Personalized" category.

After the level of autonomy and level of intelligence have been identified, the third and final task in this step is aimed at creating an information flow model for the current system. The general model of information flow (Figure 3), serves as the foundation for all resultant models of information flow when using the FAIT analysis. The FAIT user's manual provides the researcher with 12 templates that correspond to the levels of autonomy and seven templates that correspond to the levels of intelligence. Generally speaking, the level of autonomy determines which nodes are removed from the "machine output" quadrant of the general model, because they are not relevant. Similarly, the level of intelligence determines which nodes are removed from the "machine input" quadrant, because they are not relevant. The two templates that result from the current level of autonomy (simple aid) and the current level of intelligence (personalized) are fused to produce a more specific model of information flow for the current analysis. This model is shown in Figure 4.

4.2 Step 2: Decompose the Model Into Characteristics

The model of information flow that is created in the first step is used as a tool in the second step. Specifically, for each node in the model, important characteristics are listed. Although Riley (1993) does not provide a formal definition of a characteristic, here it is considered to be an important aspect of the system that can vary from a desirable to an undesirable state. Characteristics in desirable states are important to a system's proper functioning. Characteristics in undesirable states are equally important because they may lead to malfunctions in the system. For example, Riley suggests that, in a typical system, characteristics of the "Plan own action" node might be "Level of mental workload" and "Crew coordination."

Although Riley (1993) includes numerous examples, the analyst is expected to determine the relevant characteristics for the nodes in the system of interest. In determining these characteristics, Riley states that you should consider the characteristics of the system under investigation, as well as all characteristics of the operational environment and all related systems that may influence or be influenced by how the particular system works. Therefore, the current analysis includes more than the pilot, the traffic environment, and the CDTI that were identified at the onset of the analysis. At this point, the analysis also includes such things as the flight management system, air traffic controllers, fellow crew members, pilots of other aircraft, etc.

All nodes from the general model of information flow and the outcome for Step Two of the current analysis are included in Appendix B. In addition, Riley's definition (1993) of each node is provided. Nodes not included in the current model appear in gray, and justifications are made for their exclusion. Appendix B also presents a question for each node. These questions were formulated for the current analysis to assist in the identification of relevant characteristics. Finally, Appendix B presents the important characteristics that were identified for each node in the system.

A preliminary analysis yielded 116 characteristics. However, numerous characteristics yielded redundant information in later steps of the analysis. For example, the final analysis uses one characteristic, "Ownship state," to represent six characteristics that yielded redundant information in the preliminary analysis (i.e., "Ownship position," "Ownship speed," "Ownship heading," "Ownship vertical speed," "Ownship altitude," and "Ownship attitude"). The final analysis yielded a total of 68 unique characteristics. A characteristic was only counted once, even if it was associated with more than one node.

4.3 Step 3: Create a Matrix of the Characteristics and Their Interactions

The third step requires placement of characteristics in a matrix (illustrated in Table 1) that is created by placing a list of all characteristics along the left margin and the same list along the top of the matrix. Although the lists are identical, the characteristics along the left margin are referred to as the "drivers," whereas the characteristics along the top are referred to as the "receivers." These labels represent the manner in which questions are posed regarding the relation among characteristics.

The matrix is used to determine the relations among characteristics. Beginning with the first driver, the researcher asks two questions for each receiver: (1) "Is there any situation in which the driver characteristic influences the receiver characteristic?" and (2) "Is there any situation in which some limitation of the driver characteristic places a requirement on the receiver characteristic?" If the answer is "yes" to either of these questions, an entry is placed in the matrix cell where the driver and receiver intersect. Once every receiver has been considered in relation to the first driver, this process is repeated for the remaining drivers in the list.

Appendix C contains the matrix produced for the current analysis. Matrix cells that are shaded dark gray represent the negative diagonal of the matrix. These cells represent points where characteristics intersect with themselves. The lighter shade of gray and bold numbering used in other matrix cells will be explained in Step 5.

4.4 Step 4: Obtain Rough Estimates of the Relative Importance of Characteristics

The fourth step in the FAIT analysis identifies the relative importance of the characteristics by summing the rows and columns of the matrix. Row totals and ranks represent "influence," and a characteristic that is highly influential is one that affects many other characteristics of the system. Column totals and ranks represent "sensitivity," and a characteristic that is highly sensitive is one that is vulnerable to the effects of many other characteristics of the system.

Appendix D provides a convenient format for examining the influence and sensitivity scores for the current system. Table D1 presents the 68 characteristics, their respective influence scores, and their relative rank. The characteristics are presented in an order consistent with their relative rank on the influence dimension. Similarly, Table D2 presents the 68 characteristics, their respective sensitivity scores, and their relative rank. They also are presented in an order consistent with their relative rank on the sensitivity dimension.

Although there are no formal criteria for identifying the most important characteristics, Riley (personal communication, June 1, 1999) suggests concentrating on characteristics that score the highest on influence and sensitivity. Hence, the relative frequency associated with the 90th percentile point was identified for the distributions of influence and sensitivity scores. This arbitrary cutoff created a more manageable list of characteristics. Seven scores fell above the 90th percentile for both distributions, and they are denoted by a gray star in Appendix D.

The following characteristics were identified as having the most *influence* in the system and are presented in rank order:

1) Weather
2) General piloting skills
3) Time of day

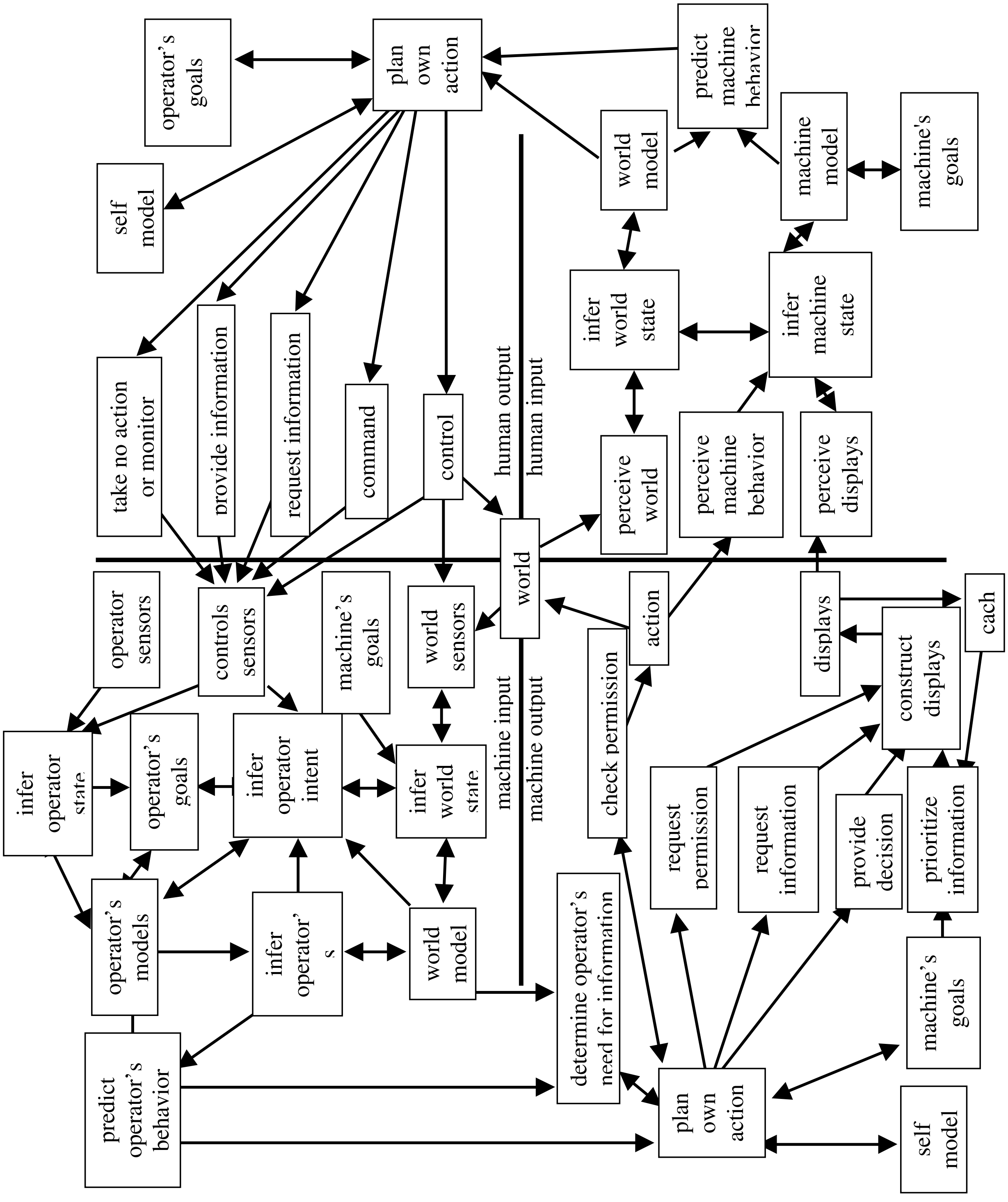

Figure 3. The general model of information flow (taken from Riley, 1993).

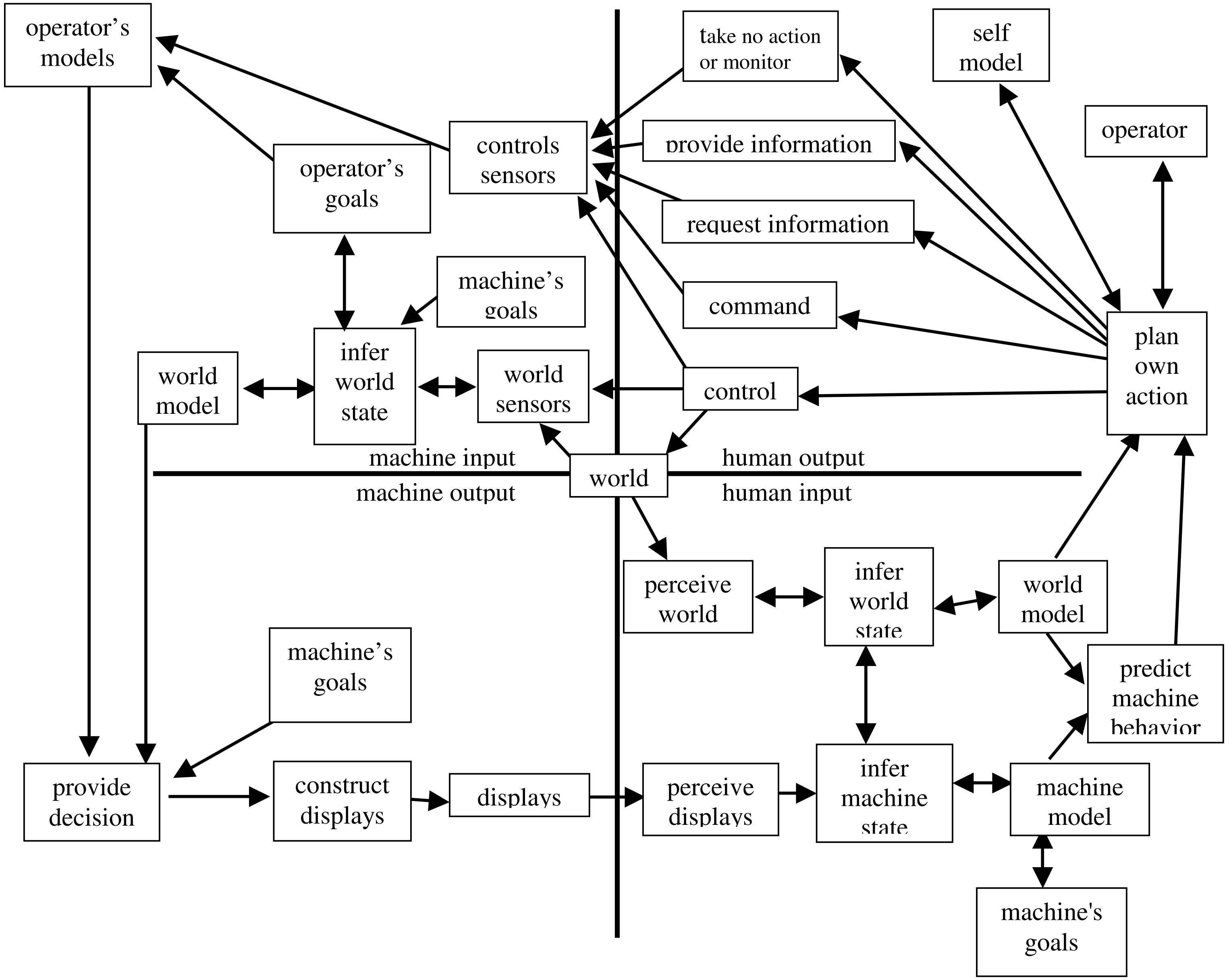

Figure 4. The model of information flow in the current system (simple aid/personalized) system.

4) Terrain
5) Ownship state
6) Level of pilot mental workload
7) Perceived time pressure

The following characteristics were identified as being the most *sensitive* (or vulnerable) and are also presented in rank order:

1) Type of action chosen by the pilot
2) Level of pilot mental workload
3) Appropriateness of planned action
4) Ownship state
5) Air traffic manger’s amount of mental workload
6) Accuracy of current machine model
7) Level of confidence in planned action

Two characteristics (“Ownship state” and “Level of pilot mental workload”) were identified as both very influential and highly sensitive. Not surprisingly, the state of the aircraft affects many aspects of the system, and at the same time, is affected by many aspects of the system. The same may be said of pilot mental workload. Given they fall above the 90th percentile point on both dimensions, these two characteristics are probably important.

Because traffic awareness is so important in the free-flight environment, two specific characteristics (viz., “Accuracy of the current machine model” and “Accuracy of pilot’s current world model”) were combined. These two characteristics are denoted by black stars in Appendix D. These two characteristics, taken together, represent the more global characteristic of “Traffic awareness.” The analysis suggests that traffic awareness is no more *influential* than the higher ranking of the two characteristics of which it is composed (i.e., “Accuracy of pilot’s current world model” and “Accuracy of current machine model”). However, traffic awareness is a more *sensitive* characteristic than when its components are examined separately. When “Accuracy of the current machine model” and “Accuracy of pilot’s current world model” are removed from the analysis and are replaced with the more global characteristic of “Traffic awareness,” the list of most sensitive characteristics appears as follows:

1) Type of action chosen by the pilot
2) Level of pilot mental workload
3) Traffic awareness
4) Appropriateness of planned action
5) Ownship state
6) Air traffic manger’s amount of mental workload
7) Level of confidence in planned action

Despite having relatively little *influence*, the *sensitivity* of traffic awareness suggests that it is a vulnerable characteristic.

In summary, Step 4 was used to identify the most important characteristics in the system. The seven most influential characteristics and seven most sensitive characteristics were extracted from the list of 68 characteristics. Two characteristics (ownship state and level of pilot mental workload) were identified as being both highly influential and highly sensitive. Therefore, these characteristics have been identified as especially important characteristics. Finally, two components, “Accuracy of the current machine model” and “Accuracy of pilot’s current world model,” were combined to create the characteristic called “Traffic awareness.” Traffic awareness was no more *influential* than the higher ranking of its two components. However, traffic awareness was one of the most sensitive characteristics of the system.

Table 1. Structure of a matrix used in the FAIT analysis.

		Receivers		
		Characteristic 1	**Characteristic 2**	**Characteristic 3**
Drivers	**Characteristic 1**			
	Characteristic 2			
	Characteristic 3			

Table 2. A sample matrix illustrating the manner in which tradeoffs are identified.

		Receivers		
		Characteristic 1	**Characteristic 2**	**Characteristic 3**
Drivers	**Characteristic 1**	▨	1	
	Characteristic 2	1	▨	
	Characteristic 3			▨

4.1 Step 5: Identify Tradeoffs in the System

The fifth step in the FAIT analysis identifies potential tradeoffs, which are found by identifying symmetrical relations within the matrix. Symmetrical relations are identified by folding the matrix along the negative diagonal and identifying entries that are superimposed on each other. These entries represent potential tradeoffs between characteristics. For example, there is one symmetrical relation in Table 2, and it is identified by the two lightly shaded cells with the bold number "1" in them. The potential for a tradeoff exists in this case, because characteristic 1 influences characteristic 2 and characteristic 2 influences characteristic 1.

The coding scheme used in Table 2 also is used in Appendix C, where lightly shaded cells that contain bolded number "1"s identify symmetries. Because symmetries in Appendix C may be difficult to visualize, Table D3 of Appendix D presents a list of the 30 characteristics that have been identified as having the potential for a tradeoff with another characteristic. Note that Table D3 consists of 124 lines, but this number is misleading. For example, "Level of pilot mental workload" is listed under "Ownship state," and "Ownship state" is listed under "Level of pilot mental workload." However, these two lines represent only one potential tradeoff. Therefore, the current analysis identified a total of 62 potential tradeoffs.

Because there are 62 potential tradeoffs, the characteristics that were identified in Step Four were used to shorten this list (Riley, personal communication, June 1, 1999), and the resulting, abbreviated matrix appears in Table D4 of Appendix D. This abbreviated matrix includes only the characteristics that are highly sensitive, highly influential, and are components of traffic awareness. Therefore, the matrix includes 13 characteristics. To make the symmetrical relations clear, the tradeoffs are coded with numbers in Table D4. For example, "Accuracy of pilot's current world model" influences "Ownship state" and vice versa. Therefore, there are two boxes in Table D4 that are assigned the number "1." The number assigned to a pair is used only to distinguish one pair from another.

As seen in Table D4, 11 potential tradeoffs require examination. Riley (1993) suggests that, in general, the most useful product of the FAIT is the documentation of possible scenarios. Potential tradeoffs are examined by creating a tradeoff scenario for each pair of characteristics that produce symmetry in the matrix. The following list provides scenarios that would exemplify the tradeoff associated with each pair of characteristics. Each scenario describes a set of possible circumstances that illustrates the potential tradeoff. If scenarios cannot be provided, then the tradeoff is probably nonexistent. However, if a reasonable scenario can be generated, then the tradeoff should be taken seriously. In other words, this task determines which of the potential tradeoffs (identified in the matrix) are true tradeoffs. Tradeoffs are examined by considering both characteristics in a pair (e.g., "Ownship state"/ "Accuracy of pilot's current world model") as a driver and a receiver. Each characteristic of the system can presumably be in various states ranging from optimal, to sub-optimal, to its poorest state. In other words, the state of each characteristic can range in terms of its desirability. For example, the accuracy of a pilot's world model can range from desirable (i.e., it might be perfect) to undesirable (i.e., the pilot currently may not have a mental model of the world situation). To represent a true tradeoff, the characteristics in a pair must be inversely related in terms of desirability; that is, an increase in the desirability of Characteristic A must lead to a decrease in the desirability of Characteristic B and vice versa. Some pairs may yield direct relations (i.e., an increase in the desirability of Characteristic A may lead to an increase in the desirability of Characteristic B and vice versa); although these pairs may be important, they do not represent true tradeoffs.

The following scenarios were used in Step Five to explore the potential for tradeoffs in the system under study.

1) Ownship State/Accuracy of Pilot's Current World Model. Tradeoff scenarios, per se, are difficult to imagine for these two characteristics. Specifically, one would not necessarily expect these two characteristics to be inversely related. Instead, a direct relation would be expected. For example, an undesirable aircraft attitude might affect the pilot's ability to obtain information from the world (and therefore limit the accuracy of the pilot's current world model). On the other hand, an inaccurate pilot world model might erroneously alter the control actions of the pilot (and create an undesirable state of ownship). While this relation appears to be a direct relation, the pairing of these two characteristics draws attention to what is probably an important synergistic relation.

2) Ownship State/Accuracy of Current Machine Model. Like the previous pairing, an inverse relation between these two characteristics is difficult to imagine. Once again, a direct relation would be expected. For example, an undesirable aircraft state (e.g., it is too close to terrain) would result in the pilot attending to information other than that presented by the CDTI. Therefore, an undesirable aircraft state would diminish the quality of the pilot's machine model, because the pilot presumably would have less knowledge of the machine state than would otherwise be the case. On the other hand, an inaccurate machine model might affect ownship state, in that the pilot's actions would not be based on all relevant information. Although the pair does not represent a tradeoff, the pairing of these two characteristics again draws attention to what is probably an important synergistic relation.

3) Ownship State/Perceived Time Pressure. Tradeoff scenarios are easily imagined for this pairing. For example, when ownship is at an undesirable altitude, speed, or attitude, the pilot would feel at least some time pressure (i.e., as the acceptability of ownship state decreases, perceived time pressure increases). If pressured by time, the pilot may make errors that worsen ownship state (i.e., as perceived time pressure increases, the acceptability of ownship state may decrease). This pairing of characteristics represents a true tradeoff.

4) Ownship State/Level of Pilot Mental Workload. Mental workload is different than the characteristics discussed thus far; *high* mental workload is an *un*desirable state. Given this distinction, this pairing does not appear to represent a tradeoff. For example, if aircraft altitude were unacceptable (i.e., the acceptability of ownship state were low), then pilot mental workload would increase in the attempt to diagnose the problem or simply attain the correct altitude (i.e., pilot mental workload also would be in an undesirable state). On the other hand, as pilot mental workload increases (i.e. reaches an undesirable state), the pilot is more likely to ignore some responsibilities. Therefore, the acceptability of ownship state could become undesirable as mental workload increases. In most cases, this pair probably has a direct relation (does not represent a tradeoff). However, the relation can be unstable due to other factors. For example, a complacent pilot would not necessarily have increases in mental workload when ownship state is undesirable.

5) Ownship State/Type of Action Chosen by the Pilot. The pairing does not appear to represent a tradeoff. Instead, the pair has a direct relation. That is, as the suitability of the chosen action decreases, the acceptability of ownship state presumably would decrease. Further, as the acceptability of ownship state decreases, the action chosen by the pilot may be less desirable (e.g., in extreme cases, the pilot may panic and use poor judgment). Again, lack of a tradeoff does not imply anything regarding the importance of this pairing.

6) Level of Air traffic Manger's Mental Workload/Level of Pilot Mental Workload. This pairing is interesting because scenarios can be imagined for both an inverse and a direct relation between the characteristics. If the pilot performs most of the duties associated with self-separation, the pilot's mental workload would be high and the ATM's mental workload would be relatively low. If a special situation arose (e.g., the ADS-B system were malfunctioning), the ATM's mental workload would increase (as the ATM would have relatively more responsibilities). At the same time, the pilot's mental workload would decrease (as the pilot would have relatively less responsibility). A direct relation also can be conceived easily. The obvious case arises when traffic is heavy. A pilot may request assistance from an ATM. However, because the ATM has high mental workload, the ATM may be unable to assist the pilot immediately. As a result, the pilot's mental workload would be relatively high. Similarly, a pilot under conditions of high mental workload may not respond immediately to an ATM. As a result, the ATM's mental workload may be increased by the pilot's high mental workload. In sum, these characteristics may sometimes represent a tradeoff, and at other times, may have a direct relation.

7) Level of Air Traffic Managers' Mental Workload/Type of Action Chosen by Pilot: This pairing of characteristics does not represent a tradeoff. When the action chosen by the pilot is less than desirable (e.g., the pilot unknowingly changes heading and creates the potential for an alert zone violation), the ATM's mental workload might increase (i.e., reach an undesirable state), because it is the ATM's duty to supervise the actions chosen by pilots. On the other hand, if an ATM has high mental workload, the ATM might not be as effective at noticing a potential conflict. Therefore, the pilot may choose an action with less information than might have otherwise been available. Therefore, when the ATM's mental workload is high (i.e., in an undesirable state), there is a better chance that the action chosen by the pilot also will be less than optimal.

8) Level of Confidence in Planned Action/Level of Pilot Workload. This pairing does not represent a tradeoff. As the pilot's level of confidence in the planned action goes down (i.e., reaches a relatively less desirable state), the pilot will search the environment in an attempt to confirm or disconfirm the adequacy of the planned action. Therefore, the pilot's mental workload will increase (will reach a relatively less desirable state). On the contrary, high pilot workload (an undesirable state) would decrease the pilot's confidence in the planned action (an undesirable state). Under high workload conditions, time may not allow the pilot to assess all relevant information and leave the pilot feeling less confident.

9) Level of Confidence in Planned Action/Type of Action Chosen by Pilot. This pair of characteristics has a direct relation. Typically, a high level of confidence yields better performance. Further, when the most appropriate action is chosen, a high level of confidence results. The only exception to this rule is in the case of overconfidence. Specifically, an inverse relation occurs when the confidence level is so high that the pilot makes uninformed decisions (e.g., ignoring crew members), and these decisions can result in a less than desirable action.

10) Perceived Time Pressure/Type of Action Chosen by Pilot Tradeoff scenarios are easily imagined for this pairing. If pressured by time, the pilot may make decisions too quickly. As a result, the chosen action may be less than satisfactory. Furthermore, if the action is inadequate (e.g., a change in heading that results in an alert zone conflict warning), the resulting situation may need to be rectified immediately.

11) Level of Pilot Mental Workload/Type of Action Chosen by Pilot. This pairing does not appear to represent a tradeoff. As pilot mental workload increases (i.e., reaches a less desirable state), the pilot is more likely to overlook relevant information. Therefore, as workload becomes less desirable, the quality of the chosen action may decrease. Furthermore, if the type of action chosen is unacceptable (e.g., aircraft is headed into terrain), then pilot mental workload naturally would increase (become less desirable) in an attempt to correct the mistake.

In sum, the goal of Step 5 was to identify tradeoffs that occur among system characteristics. In all, 62 cases were identified in which there is the potential for a tradeoff. Due to the large number of cases, the analysis was limited to include only the tradeoffs associated with the 13 most important characteristics that were identified in Step Four. These 13 characteristics yielded 11 cases of potential tradeoffs. Plausible scenarios were generated to determine which of these potential tradeoffs are truly tradeoffs. Two of the 11 pairs appear to represent true tradeoffs in the system (i.e., they are inversely related), while six pairs appear to be directly related. Three pairs appear to have unstable relations, suggesting that the circumstances are important in determining whether they represent a tradeoff or a direct relation. Although there were only two tradeoffs, an important relation was shown for every pair of characteristics.

4.6 Step 6: Identify Information Requirements

The final step in the current analysis is an identification of information requirements. First, the original matrix is used to identify errors in the system that lead to failures, incidents, or accidents (Riley, personal communication, June 1, 1999). For each potential error, an imagined scenario is documented. Once these scenarios are written, the analyst asks, "What information would assist the operator in preventing, detecting, or correcting the possible error?" Responses to this question result in a list of information requirements.

The creation of a scenario for each of the 767 pairings in the current matrix is beyond the scope of this document (i.e., there are 767 cell entries in Appendix C). Therefore, only the important characteristics, identified in Step Four, are utilized in this final step. Table D5 of Appendix D presents a matrix representing only the interactions between the important characteristics. Note that this matrix does not contain a negative diagonal because the characteristics on the left and top of the matrix are not identical. This summary matrix, which is derived from the matrix in Appendix C, yielded 51 pairs of characteristics that interact. Table D6 of Appendix D contains the 51 possible scenarios that were written for the pairings identified in Table D5. Of course, these scenarios reflect only possible interactions that could occur in a free-flight traffic environment (i.e., the environment of interest).

Although Riley (1993) suggests asking only a single question to determine information requirements, the current analysis added more structure to the task by identifying the possible error(s) that might arise in each scenario and utilizing three questions for each scenario. The first question was "*Whose knowledge* of the situation would assist in the prevention, detection, or mitigation of the error?" In this step, the human component of the system was emphasized. The second question was "*What knowledge* would assist in the prevention, detection, or mitigation of the error?" The scenarios are more helpful in identifying the required (i.e., necessary) knowledge rather than the required information. However, identifying the required knowledge is important. Available information is a necessary, but not sufficient, condition for knowledge, and the ultimate goal is to assist the pilot in obtaining knowledge. Once the necessary knowledge was identified, the third question was posed: "*What information* is necessary for the appropriate person to obtain the necessary knowledge?" The resulting information requirements for the current system are categorized according to the three aforementioned questions, and they appear in Table D7 of Appendix D.

The current analysis yielded a total of 100 information requirements. Because the information requirements for the human in the system (i.e., the pilot of ownship) and the requirements for the pilots in the world were identical, these information requirements were combined into one category (i.e., "Pilot"). Of the 100, 67 information requirements were for the air carrier pilot in the free-flight environment**,** and 33 information requirements were identified for the air traffic manager in the free-flight environment. However, one must be cognizant that, in this application of the FAIT analysis, the ATM is merely part of the world in this system (i.e., the ATM is not part of the human-machine system that is of primary interest). There probably would be many more information requirements identified for the ATM if, at the initial step of the FAIT analysis, the manager was identified as the human of primary interest.

The results obtained via the FAIT analysis were compared with those obtained from traditional task analyses. As discussed in the introduction, Endsley et al. (1998) performed a task analysis to identify information requirements for the commercial airline pilot. Endsley and Rodgers (1994) also performed a similar task analysis for an en route air traffic controller. As discussed earlier, one of the present goals was to compare the results of these two studies with the current findings.

While the precise names given to the information requirements varied slightly, 28 of the 100 information requirements identified by the FAIT are identical to those found by either Endsley et al. (1998) or Endsley and Rodgers (1994). These 28 information requirements are shaded gray in Table D7. The combined total of information requirements in the Endsely et al. (1998) and Endsley and Rodgers (1994) references exceeds 100. This amount is not surprising, given that they did not limit themselves to the task of traffic avoidance. For example, the list of information requirements in the present analysis recognizes the importance of terrain. However, because the CDTI is the only machine in the system under consideration, the only pertinent information is an alert that refers the pilot to another system. If the current analysis included all information required for piloting (as did Endsley et al.), the overall list of information requirements would be more extensive.

Given that only 28 of the information requirements identified in the FAIT analysis were redundant with that of Endsley et al. (1998) and Endsley and Rodgers (1994), the remaining 72 information requirements are unique to the analysis. The identification of unique information requirements is the result of at least four factors. *First*, unlike the research performed by Endsley, the current analysis was *not* "technology-free." In fact, the FAIT analysis is necessarily technology-inclusive. Consequently, some information requirements are very specific to the CDTI. For example, Endsley et al. (1998) list two general information requirements for the commercial airline pilot: "time available to perform tasks" and "projected time until maneuver required." An analogous, yet qualitatively different, information requirement identified in the present analysis is "time until the next alert zone contact watch/warning." The latter piece of information would allow the pilot to assess how much time can be spent on tasks other than traffic avoidance and the amount of time before a traffic avoidance might become an issue (i.e., the time until there is a watch or warning). In other words, displaying "time until the next alert zone contact watch/warning" would allow the pilot to determine the amount of time the CDTI can be ignored.

The *second*, related reason the current analysis yields unique results is that it assumes some level of automation. For example, Endsely et al. (1998) listed "projected separation between aircraft" as an information requirement, whereas the FAIT analysis identified "alert zone contact watch/warning" as an information requirement. In other words, Endsley et al. examined the current flight environment, in which the pilot is responsible for taking raw data (i.e., separation between aircraft) and formulating predictions regarding future separation. In contrast, the current analysis places the responsibility of prediction upon the CDTI. Therefore, in a free-flight environment with a CDTI, the pilot merely needs to know if there is a watch (i.e., a moderate possibility of a future alert zone conflict) or a warning (i.e., high probability of a future alert zone contact). Rather than making predictions, the pilot needs to respond appropriately when the CDTI makes predictions of impending contact.

The *third,* and related, reason the current analysis yields unique results is that it examines a free-flight environment. Unlike the previous studies, the current analysis places more traffic avoidance responsibility on the pilot (and the CDTI) than on an air traffic manager. For example, Endsley and Rodgers (1994) dedicate several information requirements to the ATM acquiring knowledge regarding the impact of proposed changes (e.g., What would happen if Aircraft X increases altitude by 1,000 feet?). However, the current research categorizes somewhat analogous information as being requirements for the pilot (i.e., "hypothetical results of planned changes").

The *fourth* reason the current analysis yields unique results is that unlike most traditional task analyses, the FAIT analysis encourages the analyst to simultaneously consider specific components of the systems (e.g., characteristics of the CDTI) and the manner in which these components interact (e.g., characteristics of the *CDTI* that might affect the *pilot*, characteristics of the *pilot* that might affect the *CDTI*, characteristics of the *world* that might affect the *pilot*, etc.). In addition, identifying the information flow in the system encourages the consideration of the real-time operation of the system. The creation of possible scenarios further enhances such consideration, in that the scenarios require deliberation regarding the effects of particular circumstances on the system when it is operating.

4.7 Concluding Remarks Regarding the Analysis

The current research used the FAIT analysis to (1) estimate the relative importance of characteristics in a system, (2) identify tradeoffs in a system, and (3) identify information requirements. However, the FAIT User's Manual (Riley, 1993) actually presents five different functional applications. The two options not applied here are related to the development of issues documents and requirements documents.

Several factors influenced the decision to exclude the issues and requirements documents in favor of the other options. The primary reason is that the issues and requirements are determined from the interactions in the matrix. Specifically, creation of an issues or a requirement document requires the creation of a scenario for every entry found in the matrix. The number of interactions identified in the current research (767 pairings) made these options impractical. Another option, in the current analysis, would be to examine only the issues and requirements associated with the important characteristics identified in Step 4. Many scenarios were written during the process of identifying tradeoffs in the system (Step 5) and identifying information requirements (Step 6). These scenarios are adequate in identifying the important issues and requirements.

The current research utilizes another option that Riley (1993) implies. Specifically, Table 3 is a reproduction of a figure presented in the FAIT User's Manual that allows for an identification of the types of issues that arise in the current system and the relative occurrence of each type.

Given the classification in Table 3, totals were calculated for each part of the matrix and are presented in Table 4. Table 4 suggests that the operator (the pilot) has the most *influential* characteristics in the system. Although not quite as great, the characteristics of the

Table 3. Classification of issues based on the layout of the matrix (adapted from Riley, 1993).

		Receivers		
		Environment	**Operator**	**Machine**
Drivers	**Environment**		**Training Issues**	
	Operator		Training Issues	Operator-Driven System Design Issues
	Machine		Training Issues	Automation Issues

Table 4. Number of interactions (% of interactions) found in each section of the matrix.

		Receivers			
		Environment	**Operator**	**Machine**	**Total Influence**
Drivers	**Environment**	70 (9%)	**180** (23%)	46 (6%)	296 (38%)
	Operator	**56** (7%)	262 (34%)	29 (4%)	347 (45%)
	Machine	33 (4%)	71 (9%)	20 (3%)	124 (16%)
	Total **Sensitivity**	159 (21%)	513 (67%)	95 (12%)	**Grand Total:** 767 (100%)

environment have substantial influence in the system, and the machine's (CDTI's) characteristics has the least amount of influence in the system. The operator, by far, has the most *sensitive* characteristics in the system. The characteristics of the environment are substantially less sensitive than the operator's characteristics, and the machine's characteristics are the least sensitive of the three. Therefore, the characteristics of the pilot have the most influence on the system, and at the same time, the pilot's characteristics are more vulnerable than any other component of the system.

The information from Table 3 and Table 4 are combined in Table 5, which identifies the types of issues that arise in the current system and the relative occurrence of each type. Few operator-driven system designs were identified. However, this finding may not be surprising, given that the NASA-AMES CDTI has only moderate "autonomy" and "intelligence" (i.e., it is a "personalized, simple aid"). Therefore, one would not expect operator characteristics to have a great amount of influence on the characteristics of the CDTI, nor would one expect the characteristics of the machine to be very vulnerable to the characteristics of the operator. Few automation issues were identified, and again this finding is probably because the NASA-AMES CDTI is only moderately "autonomous" and "intelligent." The results shown in Table 5 suggest that training issues are quite important in the system. As already stated, it is clear that operator characteristics are the most vulnerable characteristics in the system. While operator characteristics interact with characteristics from all three components of the system (i.e., the environment, the operator, and the machine), the majority of interactions are environment/operator and operator/operator interactions. Referring back to Table 4, note that over half of the entries fall in the cells where "Environment" is the driver and "Operator" is the receiver (23%), and where "Operator" is the driver and "Operator" is the receiver (34%). This finding suggests that training would be most cost-effective if the majority of training for free flight were spent concentrating on characteristics of the environment and the operator. While free flight introduces a new piece of technology (i.e., the CDTI), this analysis suggests that it is not necessarily the equipment that is cause for concern. Instead, the human factors issues (especially as they relate to traffic awareness) lie in the novel procedures, types of human interactions, and environment. This suggestion is further supported by the findings presented earlier. Almost every important characteristic that was identified in Step 4 is a characteristic of the environment or the operator; these findings will now be reviewed in terms of their practical implications.

5.0 DISCUSSION AND IMPLICATIONS OF THE FINDINGS

5.1 Summary of Findings

The system of interest is one that includes a pilot, a free-flight traffic environment, and a CDTI. The FAIT analysis yielded seven characteristics that are highly *influential* in the system: *weather*, *general piloting skills*, *time of day*, *terrain*, *ownship state* (altitude, attitude, speed, etc.), *level of pilot mental workload*, and *perceived time pressure*. Because these characteristics are highly influential, they have a great impact on the functioning of the system as a whole. Specifically, when any of these seven characteristics are in an undesirable state, they have the ability to negatively affect many other characteristics in the system. Therefore, in the process of designing technology (e.g., a CDTI) and training programs for a free-flight environment, these seven characteristics should be emphasized. Specifically, efforts should be aimed at increasing the chances that these characteristics will achieve and remain at a desirable state. Of course, some of these characteristics (i.e., weather, time of day, and terrain) cannot be controlled. In such cases, the design of technology and

Table 5. Types of issues that arise in the current system and the relative occurrence of each type.

	Training Issues	**Operator-Driven System Design Issues**	**Automation Issues**	**Miscellaneous Issues**
Number of Cases	513	**29**	20	205
Percent of Total Cases (Cases/767)	**67%**	4%	3%	27%

training programs should assist in ameliorating the undesirable effects of these characteristics.

Seven characteristics were identified as being highly *sensitive* in the free-flight traffic environment: *type of action chosen by the pilot*, *level of pilot mental workload*, *appropriateness of planned action*, *ownship state*, *level of air traffic managers' mental workload*, *accuracy of current machine model*, and *level of confidence in planned action*. These characteristics are more vulnerable than other characteristics of the system. Therefore, in the process of designing technology (e.g., a CDTI) and training programs for a free-flight environment, these seven characteristics also should be emphasized to decrease their vulnerability when related characteristics are in undesirable states.

A separate analysis on traffic awareness showed that it was not a very influential characteristic. However, it was one of the most sensitive characteristics in the system, and therefore, technology and training should be designed to aid in decreasing the vulnerability of traffic awareness.

In general, special attention should be given to cases in which the highly influential characteristics interact with the highly sensitive characteristics. The present analysis suggested that, in a free-flight environment with a CDTI, there are 51 cases where highly influential and highly sensitive characteristics interact. Furthermore, two characteristics of the system proved to be both highly influential and highly sensitive (ownship state and level of pilot mental workload). Therefore, ensuring that these two characteristics remain in a desirable state would be of utmost importance when considering the surveillance activities associated with self-separation.

Eleven potential *tradeoffs* were identified for the system. Only two of these cases resulted in a pair of characteristics being inversely related. However, pairs of characteristics that are directly related also are important because each of these pairs represents a case in which the first characteristic influences the second and vice versa (be it inversely or directly). Therefore, the interaction of all 11 pairs of characteristics should be considered in the design of tools or procedures to be used in the free-flight environment.

One of the goals of the present research was to identify and classify information requirements for pilot surveillance functions in the air carrier. One hundred *information requirements* were identified, and 67 of these information requirements were for pilots in the system. The remaining 33 information requirements were for ATMs. These information requirements might be helpful in the process of designing new technologies for pilots and ATMs. Specifically, these 100 information requirements may be utilized in the early phases of the design process. The list could be used to ensure that the necessary information is available to the appropriate party. Without such information, the pilot (or ATM) will be unable to obtain the knowledge necessary for traffic awareness.

Finally, when compared with "operator-driven system design issues" and "automation issues," the current analysis indicates that training may be the most important issue to address in the free-flight traffic environment.

5.2 The Utility of the FAIT Analysis

The second goal of the current analysis was to examine the utility of the FAIT analysis. Like traditional task analyses, the FAIT analysis allows researchers to identify information requirements. However, the FAIT analysis has value beyond that of traditional task analyses because it yields additional information. Specifically, the FAIT analysis allows the analyst to examine the relative influence and the relative sensitivity of important characteristics within the system, as well as identify potential system tradeoffs. The FAIT analysis also encourages the researcher to emphasize both the various system components (i.e., the environment, the human, and the machine) and the system as a whole. Third, the FAIT analysis also recognizes the importance of considering real-time system operation (via scenarios), and it allows the researcher to include even the psychological aspects of the human in the system (e.g., mental workload). Finally, the FAIT analysis is a useful tool for examining the effects of a particular technology in that it yields results that are specific to a task environment.

The current research included several novel procedures that proved quite useful in adding structure to the FAIT analysis. *First*, a formal definition of the term "characteristic" was composed, and *second*, a formal and unique question was used to identify characteristics for each node (cf., Appendix B). *Third*, a more structured analysis was used to extract information requirements from scenarios. Specifically, rather than asking one question about the scenario, a series of steps was performed. *Fourth*, a method by which the analyst can limit the analysis was introduced. Specifically, the 90th percentile was used in several steps to identify the important characteristics from a large pool of characteristics. Riley (personal communication, May, 1999) arbitrarily recommends limiting the overall number of characteristics to 50. However, because the FAIT analysis is meant for complex systems, it is quite likely that the number of characteristics often will exceed 50. In future research, analysts may opt to utilize the 90th percentile as a cutoff when the system is too complex to limit the characteristics to 50. A *fifth* and related point pertains to the identification of information requirements. The current research utilized only the top 10% of characteristics in the analysis, and while the scenarios were surprisingly helpful, most information requirements were identified after addressing the top 20 scenarios. Therefore, in the analysis of complex systems, utilizing only the top 5% of characteristics in the identification of information requirements may be adequate.

6.0 FUTURE RESEARCH

Future research is needed in three areas. *First*, the current analysis requires validation from domain experts. Input from domain experts would be invaluable. Their input could be obtained readily using the steps of the current analysis, that have been documented here. Domain experts would be invaluable in the validation process, as they could offer information that might further enhance the current application of the FAIT analysis. Specifically, domain experts might be queried regarding the importance of characteristics. They might also be asked about the frequency with which characteristics influence one another. Such information could be easily obtained through some sort of ranking procedure, or by using a Likert scale. Thereafter, the row and column totals found in the matrix could be weighted according to their importance and frequency of influence. In its current form, the FAIT analysis does not take the importance or frequency of occurrence into account. *Second*, the FAIT analysis should be applied to other tasks associated with surveillance functions (e.g., weather avoidance). Such an analysis would ensure that all information requirements have been identified and would provide further insight into the most important characteristics of the free-flight system as a whole. *Finally*, the FAIT analysis should be extended to include other piloting tasks. With applications of the FAIT analysis to multiple tasks, a fair comparison can be made between the FAIT analysis and traditional task analyses (e.g., Endsley et al., 1998).

7.0 REFERENCES

Cashion, P., Mackintosh, M., McGann, A., & Lozito, S. (1997). A study of commercial flight crew separation. In *Proceedings of the 16th AIAA/IEEE Digital Avionics Systems Conference* (pp. 6.3-19 – 6.3-25). New Jersey: Institute of Electrical and Electronic Engineers.

Endsley, M.R., Farley, T.C., Jones, W.M., Midkiff, A.H., & Hansman, R.J. (1998). *Situation awareness information requirements analysis for commercial airline pilots*. (NAG 2-716). National Aeronautics and Space Administration, Ames Research Center.

Endsley, M.R., & Rodgers, M.D. (1994). *Situation awareness information requirements analysis for en route air traffic control.* (DOT/FAA/AM-94/27). Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine[2].

Horvath, S. (1998). ADS-B CDTI User Interface Specification (On-line). Available: www.iimorrow.com.

Johnson, W., Battiste, V. Deizell, S., Holland, S., Belcher, S., & Jordan, K. (1997). *Development and Demonstration of a Prototype Free Flight Cockpit Display of Traffic Information.* (SAE Technical Paper No. 975554). Warrendale, PA: Society of Automotive Engineers.

Mackintosh, M., Dunbar, M., Lozito, S., Cashion, P., McGann, A., Dulchinos, V., Ruigrok, R., Hoekstra, J., Van Gent, R., & Valenti Clari, M.(1998). Self-separation from the air and ground perspective. *Air Traffic Management R&D Seminar*. Orlando, FL.

Riley, V. (1989). A general model of mixed initiative human-machine systems. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 124-8). Santa Monica, CA: The Human Factors and Ergonomics Society.

Riley, V. (1992). *Human Factors Issues of Data Link: Application of a Systems Analysis.* (SAE Technical Paper No. 922021). Warrendale, PA: Society of Automotive Engineers.

Riley, V. (1993). *Function Allocation Issues and Tradeoffs: User's Manual.* (198002014-1981). Columbus, Ohio: Honeywell Technology Center.

Riley, V. (1996). *Analyzing the dynamics of a next generation air transportation management system: Possible test scenarios for investigating human error in free flight.* (NAS2-14288). Columbus, Ohio: Honeywell Technology Center

Riley, V., Lyall, E., & Wiener, E. (1993). *Analytic Methods for Flight-Deck Automation Design and Evaluation, Phase Two Report: Pilot Use of Automation.* (DTFA01-91-C-00039). Washington, DC: Federal Aviation Administration.

RTCA (1995). *Report on the RTCA board of directors' select committee on free flight.* Washington, DC:RTCA, Incorporated.

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[2] All Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publication Web site: http://www.cami.jccbi.gov/aam-400A/Abstracts/Tech_Rep.htm.

Uhlarik, J., & Comerford, D. (2002). *A Review of Situation Awareness Literature Relevant to Pilot Surveillance Functions*. (DOT/FAA/AM-02/3). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine[2].

Wickens, C.D. (1995). Situation awareness: Impact of automation and display technology. *In Proceedings of the AGARD AMP Symposium on "Situation Awareness: Limitations and Enhancement in the Aviation Environment*," CP575. Brussels, Belgium: NATO AGARD.

Williams, K.W., & Joseph, K.M. (1998). Developing data link user-interface designs using pilot conceptual networks. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting* (pp. 77-81). Santa Monica, CA: The Human Factors and Ergonomics Society.

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[2] All Office of Aerospace Medicine technical reports are available in full-text from the Civil Aerospace Medical Institute's publication Web site: http://www.cami.jccbi.gov/aam-400A/Abstracts/Tech_Rep.htm.

8.0 APPENDIX A
FUNCTIONAL DESCRIPTION OF NASA-AMES CDTI

Figure A1 presents a snapshot of the CDTI simulation that was used for the current analysis. This figure represents the candidate CDTI in its most basic form. Regardless of operator inputs, there are several aspects of the display that remain constant in this simulation:

1) The pilot's ownship is at the bottom, center of the screen. (Here, it is represented by a filled, white chevron.)
2) The upper portion of the display presents a compass rose.
3) The upper, center of the display presents the pilot's current magnetic heading (e.g., "336").
4) A dotted white line extends from ownship and aligns with the current magnetic heading on the compass.
5) A shaded solid line (which is colored magenta in the actual display) also extends from ownship and represents the current route of ownship.
6) Shaded, star-like shapes (colored magenta in the actual display) represent way points and have shaded labels attached to them (e.g., "OAL –099").
   (a) The filled, star-like shape represents the active waypoint.
   (b) Unfilled, star-like shapes represent waypoints to be reached in the future.

Figure A1. The version of NASA's CDTI that was used in the current analysis.

7) The upper right-hand corner of the display presents the:
    (a) active waypoint (e.g., "OAL –099"),
    (b) time to the active waypoint (Note: here it reads "0000.0z," because the simulation requires adjunct software to obtain this information. Normally, the time to reach OAL –099 would be inserted in this field), and
    (c) nautical miles to the active waypoint (Again, here it reads "0.0 NM," because additional software is needed to obtain this value).
8) The upper left-hand corner of the screen displays the pilot's:
    (a) current ground speed (e.g., "GS 491"),
    (b) true air speed (e.g., "TAS 491"), and
    (c) altitude (or flight level) in hundreds of ft. (e.g., "FL400" represents an altitude of 40,000 ft.).
9) The display represents 160 miles of airspace, and 80 miles of airspace is denoted by the center tick mark labeled "80."
10) The very bottom of the display contains a toolbar that allows the pilot to manipulate the CDTI.

Outside of any manipulations the pilot can perform, there are certain aspects of the display that change with circumstances:

1) Under normal circumstances, aircraft are coded according to their altitude.
    (a) Ownship is coded white.
    (b) Aircraft at ownship's altitude are coded white.
    (c) Aircraft below ownship are coded brown.
    (d) Aircraft above ownship are coded blue.
2) Aircraft within a +/- 6,000 ft range of ownship automatically have
    (a) their altitudes displayed as a tail tag.
    (b) a one-minute predictor line extending from the aircraft symbol. (This is the case for ownship as well)
3) An arrow (↑or ↓) appears:
    (a) on the upper left-hand corner of the display (i.e., aside the altitude reading) when ownship is ascending or descending.
    (b) next to any other aircraft that is ascending or descending
4) When a potential for alert zone contact exists, the display changes in several ways. These changes are listed below and can also be seen in Figure A2.
    (a) an alert message appears on the bottom, left-hand corner of the screen. This message presents the estimated time to closest approach (e.g., "ALERT CTA: 2:17").
    (b) the datatag associated with the intruder aircraft is automatically displayed.
    (c) both the ownship and the intruder aircraft are coded differently than normal.
        (1) The chevron representing the aircraft is coded (in yellow on the actual display).
        (2) On the actual display, a (yellow) line extends from the aircraft symbol with a 2.5 nm circle at the end of it. (Overlap of two 2.5 nm circles results in the aircraft's 5 nm alert zone being contacted.) However, the portion of the one-minute predictor line is coded white.

NASA's CDTI provides the pilot with many options. In this version of the simulation, all changes to the display are performed with a mouse. All options available on the current simulation are listed below. However, they are in an order that is not consistent with the toolbar. Instead, they are in an order that is conducive to discussion.

1) Altitude may be displayed according to preference. The pilot's current selection (e.g., Abs) is indicated on the toolbar via the fourth button from the left. The pilot is able to toggle between the following two options by simply pressing the button.
    (a) Absolute altitude (e.g., "420" represents 42, 000 ft.) is displayed when the button reads "Abs."
    (b) Relative altitude (e.g., "+20" represents 2, 000 ft. above ownship) is displayed when the button reads "Rel."
2) An aircraft's complete datatag (containing an aircraft's identification number, flight level, and speed) is displayed when:
    (a) an aircraft is selected. The aircraft symbol turns green upon selection. When the mouse is moved away from the symbol, the aircraft returns to its previous color and the datatag disappears.
    (b) the IDs button is selected. In this case, all aircraft datatags are displayed until the button is selected again.
3) Datatags may be repositioned by:
    (a) selecting a particular datatag and moving it with the mouse.
    (b) selecting the S Tags button. In this case, datatags will be moved to reduce overlap and clutter. (The S Tags button will not affect any datatags that have been moved manually by the pilot.)
4) Predictor lines can be displayed for all aircraft by selecting the Pred button.

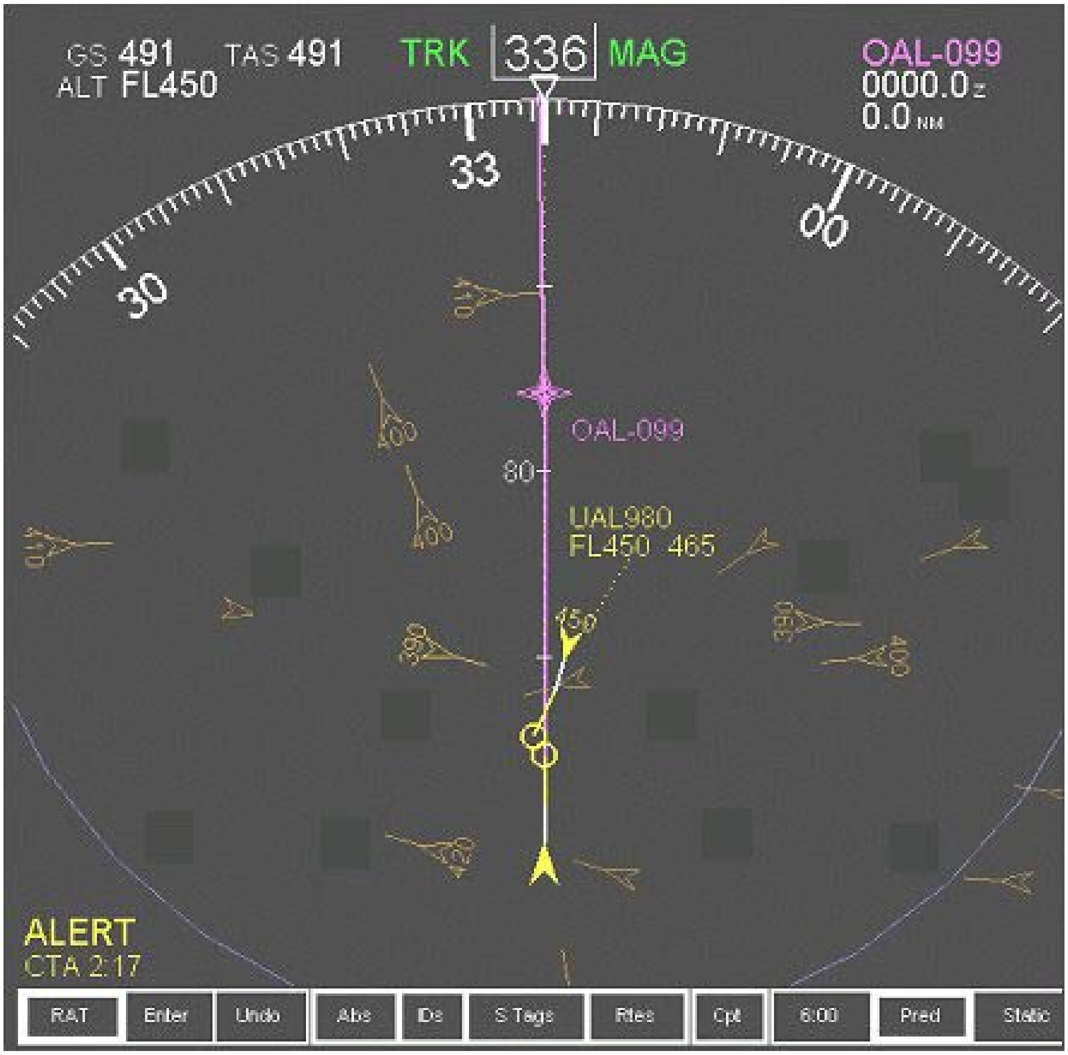


Figure A2. An example of the symbols used to display an alert zone contact on NASA's CDTI.

5) When predictor lines are displayed, two further options are available.

(a) Selecting the third button from the right changes the time represented by the predictor lines. The time represented can range from 2 to 20 minutes (in 2-minute intervals).

(b) The format of the predictor lines may be varied. The current selection is indicated on the toolbar via the first button on the left.

(1) The predictor lines are displayed in standard format when the button reads "Static." When in this mode, selecting this button causes the lines to be displayed in pulsed format.

(2) The predictor lines are displayed in a pulsed format when the button reads "Pulsed." When in this mode, the aircraft appears to "shoot" these pulses down the predictor line. This option is helpful if two aircraft have predictor lines that overlap. When in this mode, selection of the button causes the lines to be displayed in the static format.

6) The Rtes and Cpt buttons do not have functions in the current simulation.

7) The RAT button offers several options, but these options are more complex than the ones previously described. Therefore, this button is addressed below in paragraph form. The Undo and Enter buttons also are discussed in the context of the RAT button.

8.1 The Route Assessment Tool (RAT)

The RAT tool essentially serves four functions. First, it assists the pilot in assessing the effects of changes in altitude (i.e., it allows the pilot ask "what if?"). Second, after assessing these changes, it permits the pilot to accept or reject changes in altitude. The third function of the RAT tool allows the pilot to assess the effects of changes in course (again, it allows the pilot to ask "what if?). Finally, the fourth function permits the pilot to accept or reject the proposed changes in course. The following paragraphs describe the manner in which these four functions are used.

Regardless of the pilot's intentions (i.e., changing altitude or changing course), the RAT tool is always activated by simply selecting the RAT button. After selecting the button, a minimized window appears on the bottom, right-hand corner of the screen (see Figure A3).

Figure A3. The minimized window that appears immediately after the RAT button is selected.

The arrow on the right of this window (▽) is always available when the RAT is activated. Whenever this arrow is selected, it returns the window to this minimized state and moves the window to an even lower part of the screen. Therefore, the purpose of this arrow is to declutter the screen when necessary.

To use the RAT, the pilot must select the arrow pointing right (>). When this arrow is selected, the menu appears as in the bottom, right-hand corner of Figure A4. Initially, the "null point" is selected. The null point represents a point in time/space at and before which the pilot is not allowed to make changes. When the RAT is activated, this point always appears on the route line as a green dot, and the route line changes to the color green after this point in time/space. In other words, the color-coding suggests that the pilot may make changes at any point beyond the green dot. If a waypoint appears below this null point, it is represented in pink to suggest that changes cannot be made at that waypoint. If a waypoint appears above the null point, it is outlined in green, and its label is displayed in green. Because the field (box) adjacent to the label "Name" is empty and there is an orange circle around the null point, the pilot would know the null point is currently selected. Therefore, the window in Figure A4 represents a case in which the aircraft's current heading is 328 degrees and the heading at the null point will change to 336 degrees.

To make an altitude change (at a waypoint beyond the null point), the pilot again would select the arrow pointing right (>). This arrow allows the pilot to select any of the waypoints that are currently visible on the display but are beyond the null point. For example, if the CDTI appeared as in Figure A4, selecting the right arrow once would result in the window appearing as it does in Figure A5. If the pilot selected waypoint OAL –099 (as in Figure A5), a corresponding, orange circle would appear around the star representing waypoint OAL –099. The window in Figure A5 would inform the pilot that the current plan of action is to head into OAL –099 at 336 degrees and change heading to 335 degrees at that waypoint. In addition, the pilot would know that the planned altitude at that waypoint is 40,000 feet.

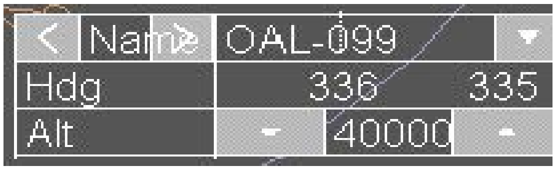
The pilot has the option of selecting any point along the route line, even if it is not pre-defined as a waypoint. To do so, the pilot places the mouse (which is the instrument for interface in this simulation) over the route line. A large arrow appears, to acknowledge that a point may be selected. Thereafter, the pilot clicks the display at the desired point. Consequently, the new waypoint appears on the display and is labeled. This new waypoint becomes an option when toggling through the name field with the right (>) and left (<) arrows.

To change altitude at any pre-defined or customized waypoint, the pilot first must select the waypoint (via the menu). Once the waypoint is selected, the pilot must click the field labeled "Alt." As shown in Figure A6, the fields corresponding to altitude are highlighted in the original window, and a scroll bar appears. The pilot is allowed to assess changes in altitude by manipulating either of the two windows. Both the arrows (▽and △) on the original window to the right and the white arrows on the scroll bar window (<< and >>) to the left allow the pilot to assess changes in altitude in intervals of 1,000 feet. The remaining white arrows on the scroll bar window (< and >) to the left allow the pilot to assess changes in intervals of 100 feet. The pilot also is able to select the pointer and slide it along the scroll bar to obtain any desired value.

When a new altitude is proposed, the CDTI changes appearance in several ways. Figure A7 provides an example of these changes. In this situation, the aircraft currently is at 40,000 feet, but an altitude of 43,000 feet is being considered. The scroll bar represents these changes by presenting the proposed altitude in both absolute and relative terms (e.g., 43,000 (+3,000)). Similarly, the "Alt s/c" field represents the altitude at which the aircraft will start its climb (i.e., 40,000 feet), and the "Alt End" field

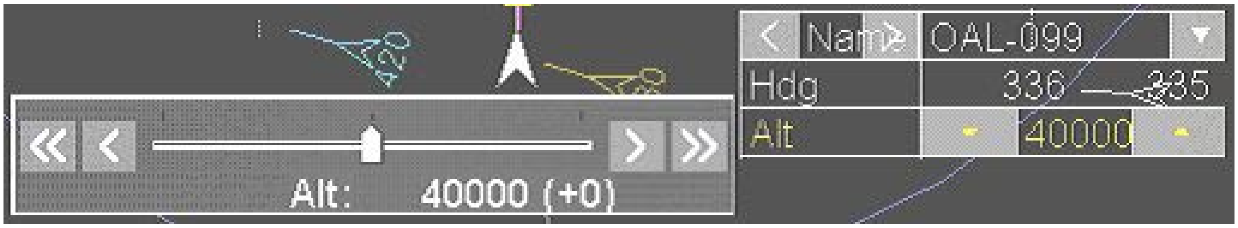
Name
Hdg 328 336
Alt 40000

Figure A4. NASA’s CDTI with the RAT tool and its respective window activated point” is selected.



Name OAL-099
Hdg 336 335
Alt 40000

Figure A5. An example of the window when a waypoint is selected.



Alt: 40000 (+0)

Name OAL-099
Hdg 336 335
Alt 40000

Figure A6. An example of the windows that are manipulated to assess changes in altitude.

indicates the altitude at which the aircraft will end (i.e., fly level at 43,000 feet).

The upper portion of the display also changes accordingly. A green diamond appears on the route line, and it is labeled "S/C." This diamond represents the point at which the aircraft must begin its ascent. The point at which the desired altitude will be reached (in this case OAL -099) is labeled with the desired altitude (i.e., FL 430). The portion of the route over which the aircraft will climb is colored in pink.

The "V-Spd" field presents the optimal vertical speed for the proposed climb (e.g., 1150 ft/min). Like proposed altitudes, variations in vertical speed can be examined. When V-Spd is selected, the arrows on the menu can be used to toggle through potential vertical speeds at one-hundred-foot intervals or the scroll bar window may be used to examine 100-foot intervals, 10-foot intervals, or any value so desired (via the scroll arrow). However, one current drawback of the simulation is that it does not put any limits on vertical speed (S. Holland, personal communication, May, 1999). That is, the CDTI simulation has not been programmed to take the limitations of an aircraft into account.

Using the RAT to assess altitude changes is helpful in couple of ways. First, it allows the pilot to visualize the space over which the proposed change will take place. For example, the diamond in Figure A7 (which is colored green in the actual display) would move farther down the screen (i.e., closer to ownship) if the pilot was interested in reaching 45,000 feet (vs. 43,000) at OAL–099. On the other hand, the diamond would move farther up the screen (i.e., closer to OAL –099) if the pilot was interested in reaching 41,000 feet at OAL–099. Furthermore, decreasing the vertical speed from 1150 to 1250 ft/min would cause the diamond to move farther down the route line (i.e., closer to ownship), whereas increasing vertical speed

Name OAL-099
V-Spd 1150
Alt End 43000
Alt s/c 40000
Alt: 43000 (+3000)

Figure A7. The CDTI as it appears when a new value for altitude is proposed.

from 1150 to 1350 ft/min would cause the diamond to move farther up the route line (i.e., closer to OAL –099). A second, and probably more important, benefit gained from the RAT is in terms of conflict alerting. If there is a possibility that the proposed change will result in an alert zone contact, ownship and the appropriate intruder aircraft are coded yellow in the actual display.

If an altitude and/or vertical speed change is assessed and the pilot finds it unacceptable, three courses of action are possible. The pilot can select the Undo button, and the values are set to their original states. On the other hand, the pilot can simply edit the proposed values. For example, the pilot may want to evaluate the effects of a descent after finding the effects of ascent unacceptable. (Proposing a descent is much the same as proposing an ascent. The only difference is that the label "S/C" is replaced with "T/D" to signify top of descent.) Finally, the pilot can select the RAT button. In which case, the values are set to their original state, and the RAT tool is deactivated.

If the pilot assesses the effects of an altitude change and would like those changes to occur, the Enter button is selected. When this button is selected, a small menu appears. Thereafter, the pilot has another chance to negate the changes by selecting "Reject." If the pilot would like the proposed changes to occur, the "Accept" option is selected. Once the proposed changes are accepted by the pilot, the display is altered. An example of the alteration can be seen in Figure A8. As can be seen in Figure A8, a dotted line (which is multicolored in pink and blue in the actual display) is used to represent the area over which the climb will occur. Blue color-coding is used to represent the area over which the aircraft will fly at the newly accepted flight level. (In cases of descent, blue is replaced by brown color-coding.)

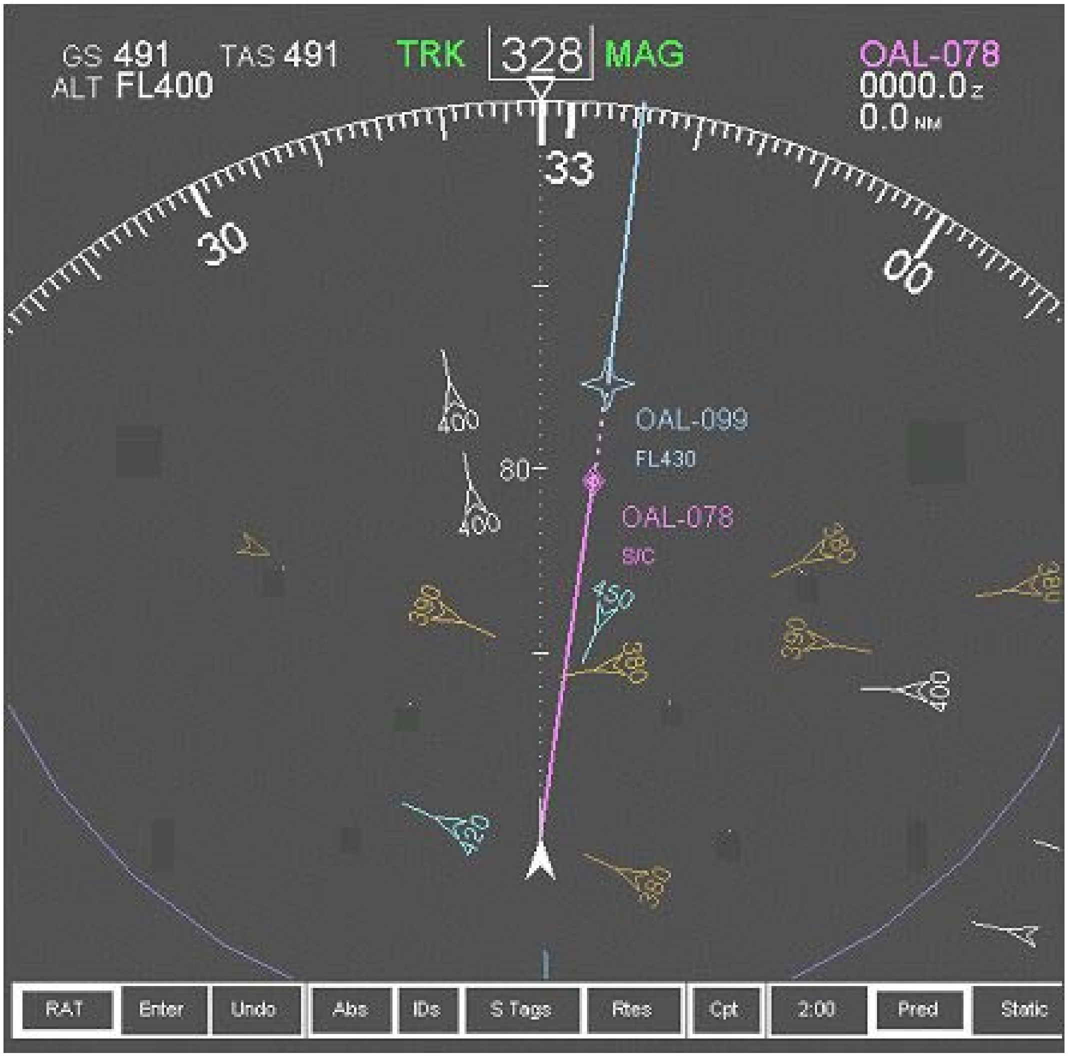


Figure A8. The CDTI as it appears when a new value for altitude is accepted.

When assessing and accepting changes in heading, the CDTI functions in much the same way as it does with altitude changes. The RAT tool first must be activated. Thereafter, a pre-existing waypoint or a customized waypoint must be selected with the mouse. For example, the pilot might select waypoint OAL –198, and the data associated with that point might appear (Figure A9). To make changes in heading, the selected waypoint is "dragged" to another location on the screen. Figure A10 presents a case where a selected waypoint, OAL –0198, has been moved to create a new waypoint, OAL –214. Notice the original waypoint, OAL 198, remains intact. However, a new waypoint appears on the display. The data for this new waypoint appear in the window, and it reflects the proposed route. In this example, the aircraft will approach waypoint OAL –214 at a heading of 25° and change to 311° when OAL –214 is reached. If the original route is used (Figure A9), the aircraft will head to waypoint OAL 198 at 335° and change to 334° when that waypoint is reached.

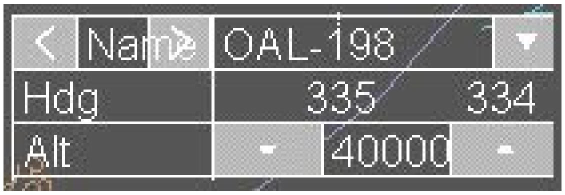

Name OAL-198
Hdg 335 334
Alt 40000

Figure A9. Data for a sample waypoint to be used in making changes to planned heading.

Therefore, the pilot is able to assess both the proposed route and its data before accepting the change. As with assessing altitude changes, the pilot also is allowed to assess

Name OAL-214
Hdg 025 311
Alt 40000

Figure A10. The CDTI as it appears when changes to planned heading are assessed.

whether a separation violation will occur as a result of the proposed changes. To accept or reject the proposed heading changes, the pilot follows the same procedures as those described above. If the pilot were to accept the changes proposed in Figure A10, the CDTI would appear as in Figure A11.

There are two important aspects of the RAT tool that require further comments. First, as a precautionary measure, the RAT tool automatically deactivates if a threat is detected in real-time. Second, one apparent drawback of the RAT is that it does not allow the pilot to assess changes in ground speed or true airspeed.

Although the important features of the simulation were summarized above, the preceding summary is not complete. In fact, pilots complete five to six hours of training before participating in research at NASA (S. Holland, personal communication, May, 1999). The interested reader should consult supplemental sources for a complete understanding of the work at NASA (e.g., Cashion et al., 1997; Johnson et al., 1997; Mackintosh et al., 1998).

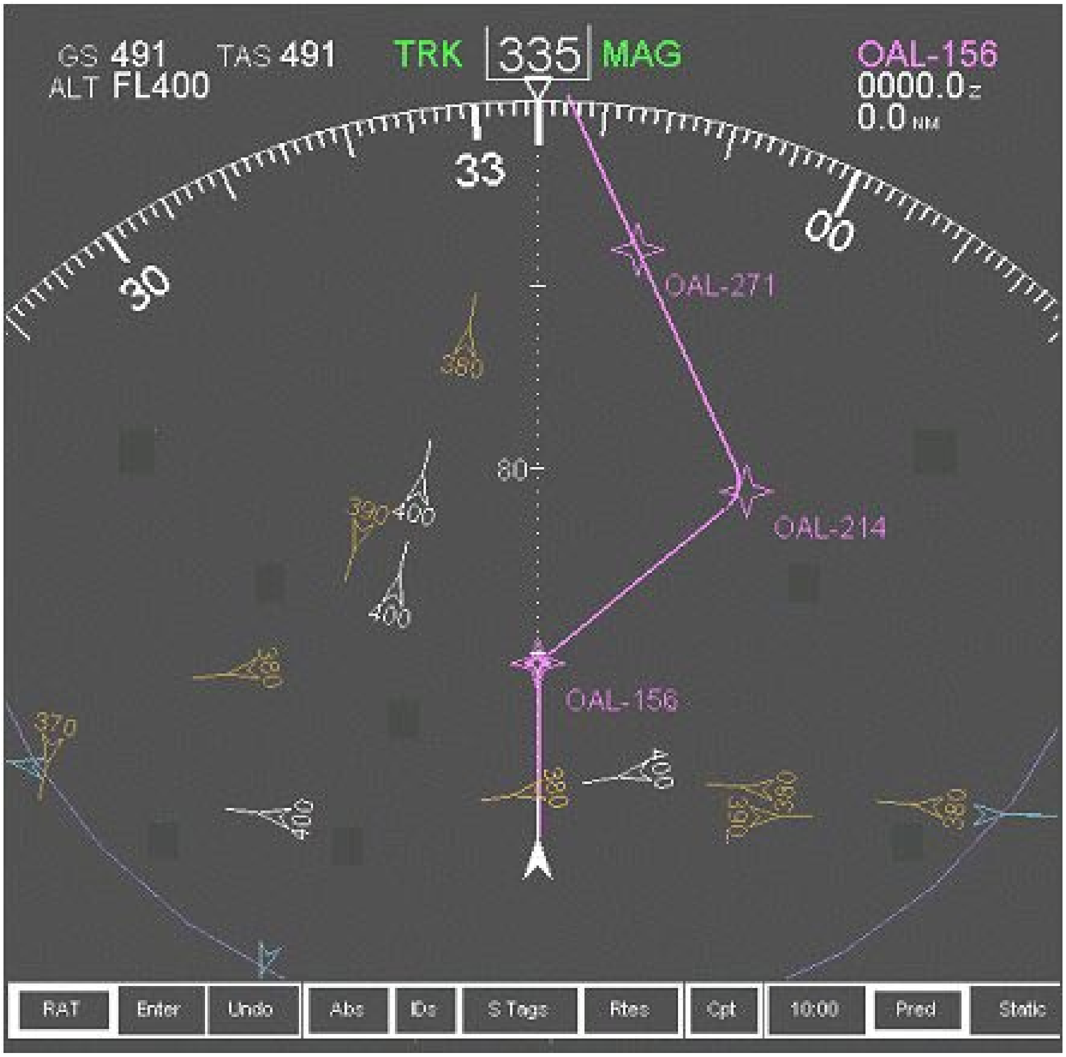


Figure A11. The CDTI as it appears when changes to heading have been accepted.

9.0 APPENDIX B

Appendix B contains Riley's definition (1993) of all nodes in the general model of information flow. If a node appears in gray, it was not included in the current model and a justification is provided for its exclusion. Each node included in the current model is accompanied by the question used to identify characteristics as well as a list of the identified characteristics.

9.1 The World

1) *World*: "Because the World node represents everything outside your particular system, parameters of the larger system that your system fits into should be included in this node" (Riley, 1993, p. 28).
  a) Our question: What affects the traffic situation in a free-flight environment (i.e., outside of the pilot and the NASA CDTI)?
  b) Characteristics:
    i) Ownship
      (1) State (i.e., position, speed, heading, vertical speed, altitude, attitude)
      (2) Destination (immediate)
      (3) Limitations/capabilities of
        (a) State of other systems (i.e., systems other than the one being examined here)
    ii) Other Aircraft
      (1) Amount of (i.e., density of traffic)
      (2) State (i.e., position, speed, heading, vertical speed, altitude, attitude)
      (3) Destination (immediate)
      (4) Limitations/capabilities of
        (a) State of other systems (i.e., systems other than the one being examined here)
      (5) Available Technology (i.e., whether they also are equipped with a CDTI)
    iii) Other Operators
      (1) Other Pilots
        (a) Levels of SA
        (b) Amount of mental workload
      (2) Air Traffic Managers
        (a) Levels of SA
        (b) Level of mental workload
    iv) Environmental Conditions
      (1) Weather
      (2) Wind
      (3) Turbulence
      (4) Time of day
      (5) Terrain
      (6) Restrictions due to traffic and facilities (e.g., airport closings or overuse)

9.2 THE HUMAN SIDE

9.2.1 Human Input

1) *Perceive World*: "This node represents the operator's access to information about the operational environment through all methods other than through the system being modeled" (Riley, 1993, p. 34).
  a) Our question: What affects the pilot's ability to perceive characteristics of the traffic situation (i.e., information other than that presented by the CDTI)?
  b) Characteristics:
    i) Out-the-window
      (1) Time spent viewing out-the-window information
      (2) Amount of information available to the pilot
    ii) Other instruments
      (1) Time spent reading other instruments
      (2) Readability of displays outside of the system (e.g., glare, color of symbols/text, size of symbols/text)

        - iii) Accuracy of pilot's previous world model (i.e., previous SA regarding the world)
        - iv) Level of pilot mental workload
        - v) Physical state of pilot (e.g., vision)
        - vi) Amount of noise in cockpit environment (e.g., may affect ability to hear radio exchanges)
        - vii) General piloting skills (e.g., experience, ability, training)
        - viii) Adequacy of physical feedback from the aircraft (e.g., can pilot perceive changes in aircraft altitude, etc.?)

2) *Perceive Machine Behavior*: "This node refers to the operators ability to sense what action the system is currently performing" (Riley, 1993, p. 34).
NOT INCLUDED- The CDTI does not perform any control actions.

3) *Perceive Displays*: "This node refers to the operators act of reading the displays" (Riley, 1993, p. 34).
- a) Our question: What affects the pilot's ability to perceive information from the CDTI?
- b) Characteristics:
    - i) Pilot skill with the CDTI (e.g., experience, ability, training)
    - ii) Time spent reading displays in the system
    - iii) Time spent reading other instruments
    - iv) Readability of displays in the system (i.e., the CDTI and the FMS)
    - v) Amount of noise in cockpit environment (e.g., may affect ability to hear auditory warnings from the CDTI)
    - vi) Accuracy of current machine model (i.e., current SA regarding the CDTI)

4) *Infer World State*: "This node refers to the operator's process of making sense out of the situation and gaining or maintaining situation awareness" (Riley, 1993, p. 34).
- a) Our question: What affects the processes involved in the pilot's gaining/maintaining awareness of the traffic situation (outside of perceptual issues)?
- b) Characteristics:
    - i) Level of pilot mental workload
    - ii) General piloting skills (e.g., experience, ability, training)
    - iii) Accuracy of pilot's previous world model (i.e., previous SA regarding the world)
    - iv) Number of errors in perceiving the world
    - v) Level of confidence in perception of the world
    - vi) Accuracy of current machine model (i.e., current SA regarding the CDTI)

5) *Infer Machine State*: "This node refers to the operator's process of understanding what the machine is doing" (Riley, 1993, p. 34).
- a) Our question: What affects the pilot's *process* of understanding of what the CDTI is doing?
- b) Characteristics:
    - i) Level of pilot mental workload
    - ii) Pilot skill with the CDTI (e.g., experience, ability, training)
    - iii) Number of errors in perceiving the CDTI
    - iv) Level of confidence in *perception* of the CDTI
    - v) Level of confidence in the CDTI (i.e., can I trust the machine?)
    - vi) Accuracy of pilot's current world model (i.e., current SA regarding the world)
    - vii) Accuracy of pilot's previous machine model (i.e., previous SA regarding the CDTI)

6) *World Model*: "This represents the operators level of understanding about the operational environment" (Riley, 1993, p. 35).
- a) Our question: What affects the pilot's current mental model of the traffic situation or what affects the operator's awareness of the traffic situation?
- b) Characteristics

    - i) Accuracy of pilot's current world model (i.e., current SA regarding the world) (This characteristic is merely a place holder, because most characteristics were identified under "Infer World State.")

7) *Machine Model*: "This represents the operator's level of understanding about the system, such as its current level of reliability" (Riley, 1993, p. 35).
  - a) Our question: What affects the pilot's current mental model of the CDTI?
  - b) Characteristics
    - i) Accuracy of current machine model (i.e., current SA regarding the CDTI) (This characteristic is merely a place holder, because most characteristics were identified under "Infer Machine State.")

8) *Machine's Goals*: "This represents the operators understanding of the machine's current goals and targets" (Riley, 1993, p. 35).
  - a) Our question: What affects the pilot's ability to understand the current "goals" of the CDTI?
  - b) Characteristics
    - i) Pilot skill with the CDTI (e.g., experience, ability, training)
    - ii) Level of confidence in the CDTI (i.e., can I trust the machine?)

9) *Predict Machine Behavior*: "This node refers to the operator's anticipation of the next actions to be taken by the machine" (Riley, 1993, p. 35).
  - a) Our question: What affects the pilot's ability to anticipate the warnings given by the CDTI?
  - b) Characteristics
    - i) Accuracy of pilot's current world model (i.e., current SA regarding the world)
    - ii) Accuracy of current machine model (i.e., current SA regarding the CDTI)

9.2.2 Human Output

1) *Plan Own Action*: "This refers to the operator's process of deciding what to do next" (Riley, 1993, p. 35).
  - a) Our question: What affects the *appropriateness* of the action chosen by the pilot?
  - b) Characteristics:
    - i) Accuracy of pilot's current world model (i.e., current SA regarding the world)
    - ii) Level of confidence in pilot's current world model (i.e., in current SA regarding the world)
    - iii) Accuracy of current machine model (i.e., current SA regarding the CDTI)
    - iv) Level of confidence in current machine model (i.e., in current SA regarding the CDTI)
    - v) Accuracy of self model
    - vi) Accuracy in predicting the machine's behavior
    - vii) Perceived time pressure
    - viii) Current team SA
    - ix) Appropriateness of operator's goals
    - x) Level of confidence in the CDTI (i.e., can I trust the machine?)
    - xi) Level of confidence in position sensors

2) *Operator's Goals*: "This node represents the operator's actual intentions, and can contain characteristics that are the operator's counterparts of the Operator's Goals and Machine's Goals nodes on the Machine side of the model" (Riley, 1993, p. 35).
  - a) Our question: What affects the intentions of the pilot?
  - b) Characteristics:
    - i) Accuracy of pilot's previous world model (i.e., previous SA regarding the world)
    - ii) Accuracy of pre-flight planning

3) *Self Model*: "This refers to the operator's assessment of his or her own current abilities or state" (Riley, 1993, p. 35).
  - a) Our question: What affects the pilot's ability to assess his/her abilities to deal with the traffic situation (phys ical and/or mental)?
  - b) Characteristics:
    - i) Level of trust in automated systems performing control actions

    - ii) Level of trust in the CDTI
    - iii) General piloting skills (e.g., experience, ability, training)

4) *Take No Action or Monitor*: "This is basically a place holder for one of the possible actions of the operator" (Riley, 1993, p. 36).
- a) Our question: What affects the pilot in accurately monitoring the CDTI?
- b) Characteristics:
    - i) Appropriateness of planned action

5) *Provide Information*: "This node represents the process by which the operator enters data into the system or provides other types of information" (Riley, 1993, p. 36).
- a) Our question: What affects the pilot in accurately providing data to the CDTI or the FMS?
- b) Characteristics:
    - i) Appropriateness of planned action
    - ii) Accuracy of the pilot in providing information to the CDTI or FMS (e.g., via keystroke errors or the pilot possesses inaccurate information)

6) *Request Information*: "This node represents the process by which the operator enters requests for information, such as calling up new display pages" (Riley, 1993, p. 36).
- a) Our question: What affects the pilot in requesting information from the CDTI (e.g., a prediction regarding the flight path of another aircraft)?
- b) Characteristics:
    - i) Appropriateness of planned action
    - ii) Accuracy of the pilot in providing information to the CDTI (e.g., via keystroke errors or the pilot possesses inaccurate information)
    - iii) Level of confidence in planned action (i.e., does the pilot need more information?)

7) *Command*: "This node represents inputs made by the operators to change the state of the system through a command to automation" (Riley, 1993, p. 36).
- a) Our question: What affects the pilot in commanding the CDTI to change its state (e.g., changing the dis play options like viewing of the datatags)?
- b) Characteristics:
    - i) Appropriateness of planned action
    - ii) Accuracy of the pilot in providing information to the CDTI (e.g., via keystroke errors or the pilot pos sesses inaccurate information)
    - iii) Level of confidence in planned action (i.e., does the pilot need more information?)

8) *Control*: "This refers to inputs made by the operators through manual control" (Riley, 1993, p. 36).
- a) Our question: What affects the pilot in controlling the aircraft's position?
- b) Characteristics:
    - i) Appropriateness of planned action
    - ii) Accuracy of physical control
        - (1) Adequacy of physical feedback from the aircraft (e.g., can pilot perceive changes in aircraft altitude, etc.?)
        - (2) Adequacy of physical feedback from the control device (e.g., force)
    - iii) Level of confidence in planned action (i.e., does the pilot need more information?)

9.3 THE MACHINE SIDE

9.3.1 Machine Input

1) *World Sensors*: "This node is intended to contain all the potential sources of information coming into the system" (Riley, 1993, p. 29).
   a) Our question: What affects the information received by the world sensors, or what affects the quality/accuracy of this information?
   b) Characteristics:
      i) Resolution and update rate of position sensors
      ii) State of position sensors hardware (i.e., functioning or malfunctioning)
      iii) Weather

2) *Control Sensors*: "This node is meant to represent all the ways the operators can put information into the system, typically through controls" (Riley, 1993, p. 29).
   a) Our question: What affects the information received by the control sensors, or what affects the quality/accuracy of this information?
   b) Characteristics:
      i) Type of action chosen by pilot
      ii) Resolution and update rate of control sensors
      iii) State of control sensors hardware (i.e., functioning or malfunctioning) for all forms of input (control devices and keypad entries)

3) *Operator Sensors*: "This node is relevant for systems that include sensors to detect the operator's cognitive or physiological state" (Riley, 1993, p. 29).
   NOT INCLUDED- The CDTI does not monitor the state of the pilot.

4) *Machine's Goals*: "This node represents the machine's current targets, operational parameters, or understanding of the current mission goals" (Riley, 1993, p. 29).
   a) Our question: What affects the "ability" of the CDTI to "understand" its role?
   b) Characteristics:
      i) Accuracy of machine's goals (e.g., did the programmer's model match the users model?)

5) *Infer Operator State*: "This node represents functions that can use the information generated by the Operator Sensors node and infer what the operator's current cognitive or physiological state is" (Riley, 1993, p. 30).
   NOT INCLUDED- The CDTI does not monitor the state of the pilot.

6) *Operator's Goals*: "This node represents the machine's understanding of the operator's current goals. It is used in models of systems that can infer the operator's intentions based partly on this understanding" (Riley, 1993, p. 29).
   a) Our question: What affects the "ability" of the CDTI to "understand" the operator's current and specific goals (e.g., what affects the ability of the CDTI to understand current heading, intended destination, etc.)?
   b) Characteristics:
      i) Accuracy of the pilot in providing information to the CDTI (e.g., via keystroke errors or the pilot possesses inaccurate information)
      ii) State (i.e., functioning or malfunctioning) of the system's hardware/software (i.e., the CDTI and FMS hardware/software and the software that allows them to "communicate)

7) *Infer Operator Intent*: "This node represents the machine's process of inferring what the operator's intentions are. This is relevant for the Operator Intent Responsive level of intelligence and up… " (Riley, 1993, p. 30).
   NOT INCLUDED- The CDTI does not infer intent and respond.

8) *Infer World State*: "This node represents the machine's process of understanding what the current state of the operational environment is, based on the information provided to it from the World Sensors" (Riley, 1993, p. 29).
  a) Our question: What affects the *processes* involved in the CDTI gaining/maintaining an "understanding" of the traffic situation?
  b) Characteristics:
    i) Accuracy of information the CDTI has regarding operator's goals
    ii) Accuracy of machine's goals
    iii) State of position sensors hardware (i.e., functioning or malfunctioning)
    iv) State (i.e., functioning or malfunctioning) of the system's hardware/software (i.e., the CDTI and FMS hardware/software and the software that allows them to "communicate)
    v) State of position sensors hardware (i.e., functioning or malfunctioning)

9) *Operator Models*: "This node represents internal representations of the human operators used by the machine to draw inferences about the operator's intention and possible future actions. Again, no such capabilities are currently provided in commercial transport equipment … This node would be relevant to a system that can merely be personalized for a particular operator" (Riley, 1993, p. 29).
  a) Our question: What affects the ability of the CDTI to "understand" what the operator wants personalized?
  b) Characteristics:
    i) Accuracy of the pilot in providing information to the CDTI (e.g., via keystroke errors or the pilot pos sesses inaccurate information)
    ii) State of control sensors hardware (i.e., functioning or malfunctioning) for all forms of input (control devices and keypad entries)
    iii) State (i.e., functioning or malfunctioning) of the system's hardware/software (i.e., the CDTI and FMS hardware/software and the software that allows them to "communicate)

10) *Infer Operator's Knowledge*: "This node is intended to represent the machine's process of inferring the operator's knowledge about the situation" (Riley, 1993, p. 31).
NOT INCLUDED- The CDTI does not infer what the pilot does/does not know.

11) *World Model*: "This node represents the machine's internal representation of the operational environment" (Riley, 1993, p. 29).
  a) Our question: What affects the CDTI's current model of the traffic situation?
  b) Characteristics:
    i) Accuracy of the machine's world model (This characteristic is merely a place holder, because most char acteristics were identified under "Infer World State.")

12) *Predict Operator's Behavior*: "This node is relevant for very complex systems that can not only infer the operator's intentions and cognitive and physiological state but can also predict potential errors the operator may make, or other actions so it can assist with those actions" (Riley, 1993, p. 31).
NOT INCLUDED- Although the RAT tool assists the operator in assessing what should be done in the future, the CDTI does not autonomously predict an operator's behavior.

9.3.2 Machine Output

1) *Determine Operator's Need for Information*: "This node contains different items depending on the overall levels of capability of the system…" (Riley, 1993, p. 31).
NOT INCLUDED- The CDTI does not decide (for the operator) what information should be displayed.

2) *Plan Own Action*: "This node represents the machine's process of planning its own future actions" (Riley, 1993, p. 32).
NOT INCLUDED- The CDTI does not plan its own actions, because it does not make any control actions.

3) *Check Permission*: "This node refers to the machine's checking whether or not the operator has granted it permission to take over operator tasks when it determines that the operator needs help" (Riley, 1993, p. 32).
NOT INCLUDED- The CDTI does not make control actions.

4) *Request Permission*: “This node refers to the machine’s process of requesting permission from the operator to take over a task which might benefit from automation but for which the operator has not granted standing permission so the automation can take over” (Riley, 1993, p. 32).
NOT INCLUDED- The CDTI does not make control actions.

5) *Request Information*: “This node refers to the machine’s process of requesting information from the operator that the machine would not otherwise have available” (Riley, 1993, p. 32).
NOT INCLUDED- The CDTI does not request information.

6) *Provide Decision*: “This represents the decisions made by the machine to the human operator” (Riley, 1993, p. 32).
   a) Our question: What affects the CDTI’s current model of the traffic situation?
   b) Characteristics: What affects the CDTI’s ability to identify other aircraft that are likely to have an alert zone contact with ownship?
      i) Accuracy of machine’s goals (e.g., the adequacy of the alerting logic used in programming)

7) *Machine’s Goals*: “This node is the same as the previous Machine’s Goals nodes. Its characteristics need not be repeated because they have already been entered into the list from the previous one” (Riley, 1993, p. 32).

8) *Self Model*: “This node represents the machine’s knowledge of its own operational state” (Riley, 1993, p. 33).
NOT INCLUDED- To our knowledge, the CDTI does not have its own built-in test.

9) *Prioritize Information*: “This node represents the process of prioritizing all the information awaiting display to the operator and putting it into a queue for assignment to display devices” (Riley, 1993, p. 33).
NOT INCLUDED- The CDTI presents all information it has available.

10) *Construct Displays*: “This node refers to the process of taking the information to be sent to the crew and generating the displays required to do so…it merely represents the process of converting the information available to the system into display formats for the crew” (Riley, 1993, p. 33).
   a) Our question: What affects the “ability” of the CDTI to process the information?
   b) Characteristics:
      i) Accuracy of the machine’s “operator’s model”
      ii) Accuracy of the machine’s world model
      iii) CDTI’s processing time

11) *Cache*: “This represents a memory store where information that cannot be displayed to the crew due to dis play limitations waits to be displayed” (Riley, 1993, p. 33).
NOT INCLUDED- The CDTI presents all information it has available.

12) *Displays*: “This node refers to the physical display devices” (Riley, 1993, p. 33).
   a) Our question: What affects the “ability” of the CDTI to *present* the information?
   b) Characteristics:
      i) Accuracy in constructing the display
      ii) Refresh rate of the CDTI

13) *Action*: “This node refers to the process of actually performing some function that changes the state of the operational environment” (Riley, 1993, p. 33).
NOT INCLUDED- The CDTI does not make any control actions.

APPENDIX C. FAIT ANALYSIS MATRIX.

				Environment																			
				Receivers																			
				A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
Environment	Drivers	A	Ownship state														1						1
		B	Ownship (immediate) destination														1						
		C	Limitations/capabilities of ownship																				
		D	State of other systems in ownship																				
		E	Amount of other aircraft												1		1						
		F	State of other aircraft														1						
		G	Destination (immediate) of other aircraft														1						1
		H	Limitations/capabilities of other aircraft												1		1						
		I	State of systems in other aircraft												1								
		J	Available technology in other aircraft												1		1						
		K	Other pilots' levels of SA						1	1					**1**		**1**						
		L	Other pilots' amount of mental workload											**1**		**1**	**1**						
		M	Air traffic managers' levels of SA											1	**1**		**1**						
		N	Level of air traffic managers' mental workload											**1**	**1**	**1**							
		O	Weather	1	1	1	1	1		1		1		1	1	1	1		**1**	1			1
		P	Wind			1									1		1	**1**					1
		Q	Turbulence			1									1		1						
		R	Time of day	1	1			1		1				1	1	1	1	1					1
		S	Terrain	1	1					1				1	1	1	1						
		T	Restrictions due to traffic and facilities		1			1		1					1		1						
Pilot	Drivers		Number of errors in perceiving the world																				
			Accuracy of pilot's previous world model	1	1																		
			Confidence in perception of the world																				
			Amount of out-the-window info. available to pilot	**1**																			
			Readability of displays outside of the system																				
			Amount of noise in cockpit environment																				
			Accuracy of pilot's current world model	**1**	1																		
			Confidence in pilot's current world model																				
			Number of errors in perceiving the AMES display	**1**																			
			Accuracy of pilot's previous machine model		1																		
			Confidence in perception of AMES display																				
			Readability of displays in the system																				
			Accuracy of current machine model	**1**	1																		
			Accuracy in predicting the machine's behavior	1	1																		
			Confidence in current machine model																				
			Pilot skill with the AMES display	1	1																		
			Confidence in position sensors	**1**	1												1						
			Appropriateness of planned action																				
			Level of confidence in planned action																				
			Appropriateness of operator's goals	1	1																		
			Accuracy of pre-flight planning	1	1											1	1						
			Accuracy of self model														1						
			Time spent viewing out-the-window info.	1										1	1	1	1						
			Time spent reading other instruments	1																			
			Time spent reading displays in the system	1	1																		
			Accuracy of physical control	1													1						
			Accuracy pilot providing info. to AMES display		1									1		1							
			Perceived time pressure	1	1																		
			Level of pilot mental workload	1	1										1		1						
			Physical state of pilot	1													1						
			General piloting skills	1	1									1	1	1	1						
			Current team SA	1	1										1		1						
			Adequacy of physical feedback from the aircraft	1																			
			Confidence auto. systems perform control actions																				
			Adequacy of physical feedback from control device	1																			
Machine	Drivers		Resolution and update rate of position sensors											1	1	1	1						
			State of position sensors hardware											1	1	1	1						
			Accuracy of the machine's world model	1	1																		
			Accuracy of info. AMES display operator's goals	1	1										1		1						
			State of the system's hardware/software	1	1										1		1						
			Resolution and update rate of control sensors	1																			
			State of control sensors hardware all forms of input	1																			
			Type of action chosen by pilot	**1**	**1**				1	**1**					**1**		**1**						
			Accuracy in constructing the display																				
			Accuracy of the machine's "operator's model"																				
			AMES display's processing time	1																			
			Refresh rate of the AMES display	1																			
			Accuracy of machine's goals	1	1									1	1		1						
			Sensitivity Total	33	24	3	1	3	2	6	0	1	0	12	23	11	31	2	1	1	0	0	5
			Sensitivity Rank	4	11	41	56	41	51	31	63	56	63	26	14	29	5	51	56	56	63	63	35

				Pilot																	
				Receivers																	
				A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Environment	Drivers		Ownship state	1		1	1	1	1	1	1	1		1	1	1				1	1
			Ownship (immediate) destination																		
			Limitations/capabilities of ownship																		1
			State of other systems in ownship	1					1	1							1				1
			Amount of other aircraft									1				1	1	1			1
			State of other aircraft														1				1
			Destination (immediate) of other aircraft																		1
			Limitations/capabilities of other aircraft														1				1
			State of systems in other aircraft														1				1
			Available technology in other aircraft																	1	
			Other pilots' levels of SA													1	1	1			
			Other pilots' amount of mental workload						1												
			Air traffic managers' levels of SA						1		1					1	1	1			1
			Level of air traffic managers' mental workload																		
			Weather	1		1	1	1		1	1	1		1	1	1		1		1	1
			Wind																		
			Turbulence								1										
			Time of day	1		1	1	1		1	1	1		1	1	1		1			
			Terrain	1		1	1			1	1									1	1
			Restrictions due to traffic and facilities																		1
Pilot	Drivers	A	Number of errors in perceiving the world							1											
		B	Accuracy of pilot's previous world model	1						1		1									
		C	Confidence in perception of the world								1										
		D	Amount of out-the-window info. available to pilot	1		1				1	1										1
		E	Readability of displays outside of the system			1				1	1										1
		F	Amount of noise in cockpit environment	1		1				1		1		1		1		1			
		G	Accuracy of pilot's current world model													1	1				1
		H	Confidence in pilot's current world model	1		1															
		I	Number of errors in perceiving the AMES display			1										1					1
		J	Accuracy of pilot's previous machine model	1						1						1					
		K	Confidence in perception of AMES display															1			
		L	Readability of displays in the system									1		1		1		1			1
		M	Accuracy of current machine model														1				1
		N	Accuracy in predicting the machine's behavior																		1
		O	Confidence in current machine model																		
		P	Pilot skill with the AMES display									1		1		1	1	1		1	1
		Q	Confidence in position sensors																		
		R	Appropriateness of planned action																		
			Level of confidence in planned action																		
			Appropriateness of operator's goals																		
			Accuracy of pre-flight planning	1	1					1	1	1				1	1	1		1	1
			Accuracy of self model	1						1		1				1	1				1
			Time spent viewing out-the-window info.	1		1				1	1							1			1
			Time spent reading other instruments	1		1				1	1					1	1	1			1
			Time spent reading displays in the system	1						1	1	1		1		1	1	1		1	1
			Accuracy of physical control																		
			Accuracy pilot providing info. to AMES display														1				1
			Perceived time pressure	1		1				1	1	1		1		1	1	1			1
			Level of pilot mental workload	1		1				1	1	1		1		1	1	1			1
			Physical state of pilot	1						1		1	1			1	1				1
			General piloting skills	1	1	1				1	1	1	1	1		1	1	1		1	1
			Current team SA		1				1	1											1
			Adequacy of physical feedback from the aircraft	1		1				1	1										1
			Confidence auto. systems perform control actions																		
			Adequacy of physical feedback from control device																		
Machine	Drivers		Resolution and update rate of position sensors									1		1		1		1		1	
			State of position sensors hardware													1		1		1	1
			Accuracy of the machine's world model													1	1	1			1
			Accuracy of info. AMES display operator's goals													1	1				1
			State of the system's hardware/software													1	1	1			1
			Resolution and update rate of control sensors																		
			State of control sensors hardware all forms of input																		
			Type of action chosen by pilot																		
			Accuracy in constructing the display									1		1	1	1	1				1
			Accuracy of the machine's "operator's model"									1					1	1	1		1
			AMES display's processing time													1		1			
			Refresh rate of the AMES display													1		1			
			Accuracy of machine's goals													1	1	1			1
			Sensitivity Total	20	3	15	4	3	5	22	17	18	2	12	4	29	25	24	1	10	39
			Sensitivity Rank	16	41	22	37	41	35	15	19	17	51	26	37	6	9	11	56	30	3

				Pilot (continued)																
				Receivers																
				A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**	**P**	**Q**
Environment	**Drivers**		Ownship state	1				**1**	**1**	**1**			**1**	**1**	**1**		**1**			
			Ownship (immediate) destination					1	1	**1**			**1**							
			Limitations/capabilities of ownship	1				1	1	1			1	1				1	1	
			State of other systems in ownship	1				1	1		1	1		1			1	1	1	1
			Amount of other aircraft	1	1			1	1	1		1	1	1			1			
			State of other aircraft		1					1			1	1						
			Destination (immediate) of other aircraft		1					1			1	1						
			Limitations/capabilities of other aircraft	1	1															
			State of systems in other aircraft		1															
			Available technology in other aircraft	1																
			Other pilots' levels of SA	1										1						
			Other pilots' amount of mental workload											**1**						
			Air traffic managers' levels of SA	1	1				1											
			Level of air traffic managers' mental workload					**1**	1	1				**1**			**1**			
			Weather	1	1	1		1	1				1	1	1				1	
			Wind								1			1				1	1	
			Turbulence	1				1	1		1	1		1				1	1	1
			Time of day	1		1		1	1	1		1		1	1		1			
			Terrain	1	1	1		1	1				1	1					1	
			Restrictions due to traffic and facilities		1	1							1	1						
Pilot	**Drivers**		Number of errors in perceiving the world																	
			Accuracy of pilot's previous world model																	
			Confidence in perception of the world					**1**	**1**					**1**						
			Amount of out-the-window info. available to pilot	1				1	1	1	1			1					1	
			Readability of displays outside of the system	1				1	1					1						
			Amount of noise in cockpit environment											1			**1**			
			Accuracy of pilot's current world model														1			
			Confidence in pilot's current world model					**1**	**1**					**1**			1		1	
			Number of errors in perceiving the AMES display									1								
			Accuracy of pilot's previous machine model																	
			Confidence in perception of AMES display							**1**				**1**						
			Readability of displays in the system	1				1	1	1		1		1						
			Accuracy of current machine model														1			
			Accuracy in predicting the machine's behavior											**1**						
			Confidence in current machine model	1				**1**		**1**				**1**			1		1	
			Pilot skill with the AMES display	1	1							1		1						
			Confidence in position sensors	1				1		**1**										
			Appropriateness of planned action																	
		A	Level of confidence in planned action					**1**	**1**	**1**				**1**			1			
		B	Appropriateness of operator's goals																	
		C	Accuracy of pre-flight planning		1															
		D	Accuracy of self model																	
		E	Time spent viewing out-the-window info.	**1**					**1**	**1**	1	1							**1**	
		F	Time spent reading other instruments	**1**				**1**		**1**	1	1							**1**	
		G	Time spent reading displays in the system	**1**				**1**	**1**		1	1							**1**	
		H	Accuracy of physical control																	
		I	Accuracy pilot providing info. to AMES display																	
		J	Perceived time pressure	1				1	1	1	1	1		1			**1**		1	
		K	Level of pilot mental workload	1			1	1	1	1	1	1					**1**		1	
		L	Physical state of pilot			1	1				1	1		1						
		M	General piloting skills	1	1	1	1	1	1	1	1	1		1			1		1	
		N	Current team SA		1								**1**	**1**						
		O	Adequacy of physical feedback from the aircraft					1	1	1	1			1					1	
		P	Confidence auto. systems perform control actions	1				**1**	**1**	**1**										
		Q	Adequacy of physical feedback from control device					1	1	1	1			1						
Machine	**Drivers**		Resolution and update rate of position sensors	1																
			State of position sensors hardware	1										1						
			Accuracy of the machine's world model		1								1	1						
			Accuracy of info. AMES display operator's goals										1	1						
			State of the system's hardware/software		1									1						
			Resolution and update rate of control sensors								1								1	1
			State of control sensors hardware all forms of input								1			1						1
			Type of action chosen by pilot	**1**									**1**	**1**			**1**		**1**	
			Accuracy in constructing the display									1		1						
			Accuracy of the machine's "operator's model"	1	1								1							
			AMES display's processing time							1										
			Refresh rate of the AMES display							1										
			Accuracy of machine's goals		1							1	1	1						
			Sensitivity Total	29	17	6	3	26	25	24	15	16	15	40	3	0	15	4	18	4
			Sensitivity Rank	6	9	31	41	8	9	11	22	21	22	2	41	63	22	37	17	37

				Machine														
				Receivers														
				A	B	C	D	E	F	G	H	I	J	K	L	M	Influence Total	Influence Rank
Environment	Drivers		Ownship state								1						24	5
			Ownship (immediate) destination								1						6	49
			Limitations/capabilities of ownship			1					1						11	27
			State of other systems in ownship			1			1	1	1		1				20	8
			Amount of other aircraft								1		1				18	10
			State of other aircraft			1											8	36
			Destination (immediate) of other aircraft								1						8	36
			Limitations/capabilities of other aircraft			1					1						8	36
			State of systems in other aircraft			1											5	56
			Available technology in other aircraft			1					1					1	7	42
			Other pilots' levels of SA			1					1						11	27
			Other pilots' amount of mental workload			1					1						7	42
			Air traffic managers' levels of SA								1						13	20
			Level of air traffic managers' mental workload								1						9	32
			Weather	1	1				1	1	1					1	42	1
			Wind		1						1					1	12	24
			Turbulence		1					1	1		1			1	18	10
			Time of day								1						31	3
			Terrain	1							1					1	25	4
			Restrictions due to traffic and facilities				1				1					1	13	20
Pilot	Drivers		Number of errors in perceiving the world								1						2	65
			Accuracy of pilot's previous world model														5	56
			Confidence in perception of the world								1						5	56
			Amount of out-the-window info. available to pilot								1						14	17
			Readability of displays outside of the system								1						9	32
			Amount of noise in cockpit environment														9	32
			Accuracy of pilot's current world model								1						7	42
			Confidence in pilot's current world model								1						8	36
			Number of errors in perceiving the AMES display								1						6	49
			Accuracy of pilot's previous machine model														4	63
			Confidence in perception of AMES display								1						4	63
			Readability of displays in the system								1						12	24
			Accuracy of current machine model								1						6	49
			Accuracy in predicting the machine's behavior								1						5	56
			Confidence in current machine model								1						7	42
			Pilot skill with the AMES display								1						14	17
			Confidence in position sensors								1						7	42
			Appropriateness of planned action								1						1	68
			Level of confidence in planned action								1						6	49
			Appropriateness of operator's goals														2	65
			Accuracy of pre-flight planning								1						16	14
			Accuracy of self model														7	42
			Time spent viewing out-the-window info.								1						18	10
			Time spent reading other instruments								1						16	14
			Time spent reading displays in the system								1						19	9
			Accuracy of physical control														2	65
			Accuracy pilot providing info. to AMES display										1				6	49
			Perceived time pressure								1						22	7
			Level of pilot mental workload								1						24	5
			Physical state of pilot								1		1				16	14
			General piloting skills								1						32	2
			Current team SA								1						12	24
			Adequacy of physical feedback from the aircraft								1						13	20
			Confidence auto. systems perform control actions								1						5	56
			Adequacy of physical feedback from control device														6	49
Machine	Drivers	A	Resolution and update rate of position sensors			1											11	27
		B	State of position sensors hardware	1		1					1						13	20
		C	Accuracy of the machine's world model														9	32
		D	Accuracy of info. AMES display operator's goals								1						10	31
		E	State of the system's hardware/software			1	1				1	1	1	1	1		17	13
		F	Resolution and update rate of control sensors			1					1			1			7	42
		G	State of control sensors hardware all forms of input						1		1						6	49
		H	Type of action chosen by pilot														11	27
		I	Accuracy in constructing the display														8	36
		J	Accuracy of the machine's "operator's model"														8	36
		K	AMES display's processing time								1						5	56
		L	Refresh rate of the AMES display								1						5	56
		M	Accuracy of machine's goals								1						14	17
			Sensitivity Total	3	3	12	2	0	3	3	53	1	6	2	1	6		
			Sensitivity Rank	41	41	26	51	63	41	41	1	56	31	51	56	31		

APPENDIX D

Table D1. Relative Influence of Characteristics.

Characteristic	**Score**	**Rank**
Weather	*42*	*1*
General piloting skills	*32*	*2*
Time of day	*31*	*3*
Terrain	*25*	*4*
Ownship state	*24*	*5*
Level of pilot mental workload	*24*	*5*
Perceived time pressure	*22*	*7*
90th Percentile →		
State of other systems in ownship	*20*	*8*
Time spent reading displays in the system	*19*	*9*
Amount of other aircraft	*18*	*10*
Turbulence	*18*	*10*
Time spent viewing out-the-window information	*18*	*10*
State of the system's hardware/software	*17*	*13*
Accuracy of pre-flight planning	*16*	*14*
Time spent reading other instruments	*16*	*14*
Physical state of pilot	*16*	*14*
Amount of out-the-window information available to the pilot	*14*	*17*
Pilot skill with the AMES display	*14*	*17*
Accuracy of machine's goals	*14*	*17*
Air traffic managers' levels of SA	*13*	*20*
Restrictions due to traffic and facilities	*13*	*20*
Adequacy of physical feedback from the aircraft	*13*	*20*
State of position sensors hardware	*13*	*20*
Wind	*12*	*24*
Readability of displays in the system	*12*	*24*
Current team SA	*12*	*24*
Limitations/capabilities of ownship	*11*	*27*
Other pilots' levels of SA	*11*	*27*
Resolution and update rate of position sensors	*11*	*27*
Type of action chosen by pilot	*11*	*27*
Accuracy of information the AMES display has regarding operator's goals	*10*	*31*
Level of air traffic managers' mental workload	*9*	*32*
Readability of displays outside of the system	*9*	*32*
Amount of noise in cockpit environment	*9*	*32*
Accuracy of the machine's world model	*9*	*32*
State of other aircraft	*8*	*36*
Destination (immediate) of other aircraft	*8*	*36*
Limitations/capabilities of other aircraft	*8*	*36*
Level of confidence in pilot's current world model	*8*	*36*
Accuracy in constructing the display	*8*	*36*
Accuracy of the machine's "operator's model"	*8*	*36*
Available technology in other aircraft	*7*	*42*
Other pilots' amount of mental workload	*7*	*42*
Accuracy of pilot's current world model ★	*7*	*42*
Level of confidence in current machine model	*7*	*42*
Level of confidence in position sensors	*7*	*42*
Accuracy of self model	*7*	*42*
Resolution and update rate of control sensors	*7*	*42*
Ownship (immediate) destination	*6*	*49*
Number of errors in perceiving the AMES display	*6*	*49*
Accuracy of current machine model ★	*6*	*49*
Level of confidence in planned action	*6*	*49*
Accuracy of the pilot in providing information to the AMES display	*6*	*49*
Adequacy of physical feedback from the control device	*6*	*49*
State of control sensors hardware for all forms of input	*6*	*49*
State of systems in other aircraft	*5*	*56*
Accuracy of pilot's previous world model	*5*	*56*
Level of confidence in perception of the world	*5*	*56*
Accuracy in predicting the machine's behavior	*5*	*56*
Level of confidence in automated systems performing control actions	*5*	*56*
AMES display's processing time	*5*	*56*
Refresh rate of the AMES display	*5*	*56*
Accuracy of pilot's previous machine model	*4*	*63*
Level of confidence in perception of the AMES display	*4*	*63*
Number of errors in perceiving the world	*2*	*65*
Appropriateness of operator's goals	*2*	*65*
Accuracy of physical control	*2*	*65*
Appropriateness of planned action	*1*	*68*

Table D2. Relative Sensitivity of Characteristics.

Characteristic	Score	Rank
Type of action chosen by pilot	53	1
Level of pilot mental workload	40	2
Appropriateness of planned action	39	3
Ownship state	33	4
Level of air traffic managers' mental workload	31	5
Accuracy of current machine model ★	29	6
Level of confidence in planned action	29	6
Time spent viewing out-the-window information	26	8
Accuracy in predicting the machine's behavior	25	9
Time spent reading other instruments	25	9
Ownship (immediate) destination	24	11
Level of confidence in current machine model	24	11
Time spent reading displays in the system	24	11
Other pilots' amount of mental workload	23	14
Accuracy of pilot's current world model ★	22	15
Number of errors in perceiving the world	20	16
Number of errors in perceiving the AMES display	18	17
Level of confidence in automated systems performing control actions	18	17
Level of confidence in pilot's current world model	17	19
Appropriateness of operator's goals	17	19
Accuracy of the pilot in providing information to the AMES display	16	21
Level of confidence in perception of the world	15	22
Accuracy of physical control	15	22
Perceived time pressure	15	22
Current team SA	15	22
Other pilots' levels of SA	12	26
Level of confidence in perception of the AMES display	12	26
Accuracy of the machine's world model	12	26
Air traffic managers' levels of SA	11	29
Level of confidence in position sensors	10	30
Destination (immediate) of other aircraft	6	31
Accuracy of pre-flight planning	6	31
Accuracy of the machine's "operator's model"	6	31
Accuracy of machine's goals	6	31
Restrictions due to traffic and facilities	5	35
Amount of noise in cockpit environment	5	35
Amount of out-the-window information available to the pilot	4	37
Readability of displays in the system	4	37
Adequacy of physical feedback from the aircraft	4	37
Adequacy of physical feedback from the control device	4	37
Limitations/capabilities of ownship	3	41
Amount of other aircraft	3	41
Accuracy of pilot's previous world model	3	41
Readability of displays outside of the system	3	41
Accuracy of self model	3	41
Physical state of pilot	3	41
Resolution and update rate of position sensors	3	41
State of position sensors hardware	3	41
Resolution and update rate of control sensors	3	41
State of control sensors hardware for all forms of input	3	41
State of other aircraft	2	51
Weather	2	51
Accuracy of pilot's previous machine model	2	51
Accuracy of information the AMES display has regarding operator's goals	2	51
AMES display's processing time	2	51
State of other systems in ownship	1	56
State of systems in other aircraft	1	56
Wind	1	56
Turbulence	1	56
Pilot skill with the AMES display	1	56
Accuracy in constructing the display	1	56
Refresh rate of the AMES display	1	56
Limitations/capabilities of other aircraft	0	63
Available technology in other aircraft	0	63
Time of day	0	63
Terrain	0	63
General piloting skills	0	63
State of the system's hardware/software	0	63

90th Percentile →

Table D3. Complete List of Tradeoffs.

Characteristic	Tradeoff Characteristic
Ownship state	Level of pilot mental workload
	Type of action chosen by pilot
	Time spent viewing out-the-window information
	Time spent reading displays in the system
	Time spent reading other instruments
	Current team SA
	Perceived time pressure
	Accuracy of pilot's current world model ★
	Level of confidence in position sensors
	Amount of out-the-window information available to the pilot
	Number of errors in perceiving the AMES display
	Accuracy of current machine model ★
	Physical state of pilot
Level of pilot mental workload	Ownship state
	Type of action chosen by pilot
	Level of air traffic managers' mental workload
	Current team SA
	Other pilots' amount of mental workload
	Level of confidence in planned action
	Level of confidence in perception of the world
	Level of confidence in pilot's current world model
	Level of confidence in current machine model
	Level of confidence in perception of the AMES display
	Accuracy in predicting the machine's behavior
Type of action chosen by pilot	Ownship state
	Level of pilot mental workload
	Level of air traffic managers' mental workload
	Current team SA
	Other pilots' amount of mental workload
	Level of confidence in planned action
	Perceived time pressure
	Level of confidence in automated systems performing control actions
	Ownship (immediate) destination
	Destination (immediate) of other aircraft
Time spent viewing out-the-window information	Ownship state
	Time spent reading displays in the system
	Level of air traffic managers' mental workload
	Time spent reading other instruments
	Level of confidence in planned action
	Level of confidence in perception of the world
	Level of confidence in pilot's current world model
	Level of confidence in automated systems performing control actions
	Level of confidence in current machine model
Time spent reading displays in the system	Ownship state
	Time spent viewing out-the-window information
	Time spent reading other instruments
	Level of confidence in planned action
	Level of confidence in automated systems performing control actions
	Ownship (immediate) destination
	Level of confidence in current machine model
	Level of confidence in perception of the AMES display
	Level of confidence in position sensors
Level of air traffic managers' mental workload	Level of pilot mental workload
	Type of action chosen by pilot
	Time spent viewing out-the-window information
	Current team SA
	Other pilots' amount of mental workload
	Other pilots' levels of SA
	Air traffic managers' levels of SA
Time spent reading other instruments	Ownship state
	Time spent viewing out-the-window information
	Time spent reading displays in the system
	Level of confidence in planned action
	Level of confidence in perception of the world
	Level of confidence in pilot's current world model
	Level of confidence in automated systems performing control actions

Table D3. Complete List of Tradeoffs (continued).

Current team SA	Ownship state
	Level of pilot mental workload
	Type of action chosen by pilot
	Level of air traffic managers' mental workload
	Perceived time pressure
	Accuracy of pilot's current world model ★
	Amount of noise in cockpit environment
Other pilots' amount of mental workload	Level of pilot mental workload
	Type of action chosen by pilot
	Level of air traffic managers' mental workload
	Other pilots' levels of SA
	Air traffic managers' levels of SA
Level of confidence in planned action	Level of pilot mental workload
	Type of action chosen by pilot
	Time spent viewing out-the-window information
	Time spent reading other instruments
	Time spent reading displays in the system
Level of confidence in perception of the world	Level of pilot mental workload
	Time spent viewing out-the-window information
	Time spent reading other instruments
	Level of confidence in pilot's current world model
Level of confidence in pilot's current world model	Level of pilot mental workload
	Time spent viewing out-the-window information
	Time spent reading other instruments
	Level of confidence in perception of the world
Perceived time pressure	Ownship state
	Type of action chosen by pilot
	Current team SA
	Ownship (immediate) destination
Level of confidence in automated systems performing control actions	Type of action chosen by pilot
	Time spent viewing out-the-window information
	Time spent reading displays in the system
	Time spent reading other instruments
Ownship (immediate) destination	Type of action chosen by pilot
	Time spent reading displays in the system
	Perceived time pressure
Level of confidence in current machine model	Level of pilot mental workload
	Time spent viewing out-the-window information
	Time spent reading displays in the system
Other pilots' levels of SA	Level of air traffic managers' mental workload
	Other pilots' amount of mental workload
Air traffic managers' levels of SA	Level of air traffic managers' mental workload
	Other pilots' amount of mental workload
Accuracy of pilot's current world model ★	Ownship state
	Current team SA
Level of confidence in perception of the AMES display	Level of pilot mental workload
	Time spent reading displays in the system
Level of confidence in position sensors	Ownship state
	Time spent reading displays in the system
Destination (immediate) of other aircraft	Type of action chosen by pilot
Weather	Wind
Wind	Weather
Amount of out-the-window information available to the pilot	Ownship state
Amount of noise in cockpit environment	Current team SA
Number of errors in perceiving the AMES display	Ownship state
Accuracy of current machine model ★	Ownship state
Accuracy in predicting the machine's behavior	Level of pilot mental workload
Physical state of pilot	Ownship state

Table D4. Tradeoffs Between Important Characteristics.

Receivers	Ownship state	Level of air traffic managers' mental workload	Weather	Time of day	Terrain	Accuracy of pilot's current world model	Accuracy of current machine model	Appropriateness of planned action	Level of confidence in planned action	Perceived time pressure	Level of pilot mental workload	General piloting skills	Type of action chosen by pilot
Drivers													
Ownship state	▨					1	2			3	4		5
Level of air traffic managers' mental workload		▨									6		7
Weather			▨										
Time of day				▨									
Terrain					▨								
Accuracy of pilot's current world model	1					▨							
Accuracy of current machine model	2						▨						
Appropriateness of planned action								▨					
Level of confidence in planned action									▨		8		9
Perceived time pressure	3									▨			10
Level of pilot mental workload	4	6							8		▨		11
General piloting skills												▨	
Type of action chosen by pilot	5	7							9	10	11		▨

Table D5. Matrix Representing the Relations Between Only the Most Important Characteristics.

Receivers	Ownship state	Level of air traffic managers' mental workload	Accuracy of pilot's current world model	Accuracy of current machine model	Appropriateness of planned action	Level of confidence in planned action	Level of pilot mental workload	Type of action chosen by pilot	***INFLUENCE SUBTOTAL***
Drivers									
Ownship state	▨	1	1	1	1	1	1	1	***7***
Weather	1	1	1	1	1	1	1	1	***8***
Time of day	1	1	1	1		1	1	1	***7***
Terrain	1	1	1		1	1	1	1	***7***
Perceived time pressure	1		1	1	1	1	1	1	***7***
Level of pilot mental workload	1	1	1	1	1	1	▨	1	***7***
General piloting skills	1	1	1	1	1	1	1	1	***8***
SENSITIVITY SUBTOTAL	***6***	***6***	***7***	***6***	***6***	***7***	***6***	***7***	

Table D6. Scenarios Representing a Combination of the Most Influential and Most Sensitive Characteristics.

Driver/Receiver

1. *Ownship state/Level of air traffic managers' mental workload*: For obvious reasons, the state of ownship affects the air traffic manager's amount of mental workload. For example, if the position of ownship is within 5 nm of another aircraft, the free-flight environment requires the air traffic manager to assume responsibilities that are otherwise the pilot's responsibilities. Therefore, the imagined scenario is one in which the air traffic manager's amount of mental workload is high because ownship's alert zone contact has been intruded.

2. *Ownship state/Accuracy of pilot's current world model*: This pairing was already addressed when tradeoffs were examined, and it was identified as having a direct relation. However, what is currently of interest is the influence of ownship state on the accuracy of the pilot's current world model. As stated when addressing tradeoffs, an undesirable aircraft attitude might affect the pilot's ability to obtain information from the world (and therefore negatively affect the accuracy of the world model). Therefore, the imagined scenario is one in which the world model is inaccurate because ownship state does not allow the pilot to obtain the relevant information from the world.

3. *Ownship state/Accuracy of current machine model*: These two characteristics were already identified as having a tradeoff relation. However, what is currently of interest is only the influence of ownship state on the accuracy of the pilot's current machine model. There are many cases in which ownship state would have a negative effect on the current machine model. Specifically, when ownship state is undesirable in any manner that is unrelated to traffic (e.g., altitude is too low given the weather situation), the pilot presumably would spend more time attending to other displays, out-the-window-information, and control devices. Therefore, the imagined scenario is one in which the machine model is inaccurate because the pilot is attending to sources other than the CDTI.

4. *Ownship state/Appropriateness of planned action*: For obvious reasons, the state of ownship has an effect on whether the planned action is appropriate. For example, if ownship is suddenly in an undesirable state (e.g., on a course or at a speed that will lead to an alert zone contact), the action that is planned may be inappropriate (e.g., the planned action may be to take no action). Similarly, if ownship is in a desirable state, the planned action may be inappropriate (e.g., changes in heading create an alert zone contact). Therefore, the imagined scenario is one in which the state of the ownship causes the planned action to be one that is inappropriate.

5. *Ownship state/Level of confidence in planned action*: A scenario is easily imagined in which ownship state influences the pilot's level of confidence in the planned action. Specifically, if the position of ownship is such that an alert zone conflict is occurring, the pilot is required to make a decision quickly. Therefore, it might be difficult for the pilot to have complete confidence in such a decision.

6. *Ownship state/Level of pilot mental workload*: These two characteristics were already identified as having a tradeoff relation. While the inverse relation is discussed below, what is currently of interest is only the influence of ownship state on the level of pilot mental workload. As discussed in terms of tradeoffs, an example of this pairing would occur if aircraft altitude were unacceptable (i.e., the current altitude will create an alert zone contact). Pilot mental workload problem would increase in the attempt to rectify the problem (e.g., attain the correct altitude or contact the appropriate pilot).

7. *Ownship state/Type of action chosen by the pilot*: These characteristics were already identified as having a direct relation in the section that addresses tradeoffs. As indicated in that section, the acceptability of ownship state affects the action chosen by the pilot, in that as ownship state becomes less desirable the action chosen by the pilot may be less desirable (e.g., in extreme cases, the pilot may panic and use poor judgment).

8. *Weather/Ownship state*: For obvious reasons (e.g., lightning, wind), the weather can affect the state of ownship and the pilot's ability to control ownship.

9. *Weather/ Level of air traffic managers' mental workload*: Weather affects the air traffic manager's amount of workload. Under normal conditions, the air traffic manager is responsible only for monitoring the ability of the pilots to maintain self-separation. With the advent of a storm, the air traffic manager must also monitor the ability of the pilots to avoid weather formations. Under severe weather conditions, the air traffic manager presumably will receive more verbal reports regarding the presence and severity of the current weather situation.

10. *Weather/Accuracy of pilot's current world model*: The weather may affect the pilot's current world model in cases where it limits visibility. Therefore, the pilot may lose visual contact with nearby aircraft. Because the pilot may have to concentrate on controlling the aircraft, it indirectly may affect the model by diverting attention from all other relevant information in the world (traffic in this case).

11. *Weather/Accuracy of current machine model*: Similar to the previous effect, weather may affect the machine model by diverting attention from the CDTI.

12. *Weather/Appropriateness of planned action*: For obvious reasons, the surrounding weather situation has an effect on whether the planned action is appropriate. For example, under normal circumstances, no action by the pilot may be appropriate. However, planning the same lack of action may be inappropriate if the aircraft is headed for a weather formation.

13. *Weather/Level of confidence in planned action*: Poor weather may affect the level of confidence in planned action because of its mere existence (i.e., the pilot may wonder whether the aircraft will avoid the weather given the current plans). Here, what is more important is the effect of the weather on the traffic situation. Imagine ownship is in congested airspace and the weather is poor. Due to low visibility, the pilot may have relatively little confidence that the planned action will result in the successful avoidance of all aircraft alert zones.

14. *Weather/Level of pilot mental workload*: Because of the mere existence of poor weather, the pilot's mental workload increases. Specifically, the pilot's attention may be focused upon the avoidance of the weather and controlling the aircraft within these conditions. Therefore, in poor weather conditions, the pilot's ability to monitor the traffic situation (whether through the world or the CDTI) may be hindered by the limits of working memory.
15. *Weather/Type of action chosen by the pilot*: This relation is similar to the one between Weather and Appropriateness of Planned Action. For obvious reasons, the surrounding weather situation has an effect on whether the control action is appropriate. For example, under normal circumstances, no action by the pilot may be appropriate. However, under poor weather conditions, the same lack of action may place the aircraft in a weather formation.

16. *Time of day/Ownship state*: The pilot's previous actions may have been related to whether the aircraft was flying under IFR or VFR rules. Therefore, time of day can have an indirect effect on the acceptability of the current state of ownship.

17. *Time of day/ Level of air traffic managers' mental workload*: Although it depends on the sector, the volume of traffic varies with the time of day. Therefore, air traffic manager's workload varies with the time of day.

18. *Time of day/Accuracy of pilot's current world model*: Too much sunlight and lack of sunlight can affect the pilot's ability to view out-the-window information. Therefore, the accuracy of the pilot's current world model can vary with the time of day.

19. *Time of day/Accuracy of current machine model*: Glare and direct sun light can affect the pilot's ability to view the CDTI. Therefore, the accuracy of the current machine model can vary with the time of day.

20. *Time of day/Level of confidence in planned action*: Volume of traffic and visibility both vary with time of day. Daytime traffic volumes and nighttime low visibility conditions will both decrease the pilot's confidence that alert zone conflicts will be avoided successfully.

21. *Time of day/Level of pilot mental workload*-Similar to the previous description, daytime traffic volumes and nighttime low visibility conditions will both increase the pilot's level of mental workload. As a result, the pilot's attention may not be directed at the most relevant information/

22. *Time of day/Type of action chosen by the pilot*: The action chosen by the pilot may vary with time of day. Nighttime conditions call for IRF rules, and the pilot is working under conditions of little or no visibility. Daytime conditions, on the other hand, may yield high traffic volumes and strong sunlight. Given these hindrances, the action chosen by the pilot may sometimes be inappropriate.

23. *Terrain/Ownship state*: Assuming the pilot was accurate, the flight plans take the terrain into account. Therefore, the terrain presumably affects ownship state. However, if the pilot fails to remember the geography, a situation could arise where an alert zone contact is unavoidable (i.e., two planes are trapped by geographical boundaries).

24. *Terrain/ Level of air traffic managers' mental workload*: Presumably, the effects of terrain would vary between air traffic managers (rather than within an air traffic manager). Specifically, a sector with dangerous terrain would be more difficult to monitor than a sector with flat terrain. Therefore, an air traffic manager assigned to a sector with dangerous terrain might spend relatively more time assisting aircraft in avoiding terrain. As a result, such an air traffic manager might be less effective at monitoring the self-separation of aircraft.

25. *Terrain/Accuracy of pilot's current world model*: The accuracy of the pilot's current world model might be sacrificed if terrain occluded out-the-window information. In addition, given knowledge of perceptual illusions, the pilot may misjudge distance to a particular geographical formation (e.g., a mountain). Misjudging distance to the terrain may also lead to misjudgments regarding the position of visible aircraft.

26. *Terrain/Appropriateness of planned action*: For obvious reasons, the surrounding terrain has an effect on whether the planned action is appropriate. For example, if the pilot plans an action that deviates from the original flight plan, the newly planned action may be appropriate. However, the same change of plans may result in a collision with terrain or a situation where the terrain makes an alert zone contact unavoidable (i.e., two aircraft are trapped).
27. *Terrain/Level of confidence in planned action*: Because terrain can occlude out-the-window information, the pilot may have relatively little confidence that the planned action will result in the successful avoidance of alert zones.

28. *Terrain/Level of pilot mental workload*: When an aircraft nears potentially dangerous terrain, the pilot is more likely to utilize attentional resources on the avoidance of the terrain. Therefore, the pilot is more likely to ignore traffic information from both the CDTI and the forward field of view.

29. *Terrain/Type of action chosen by the pilot*: The pilot may suddenly change the state of the aircraft if the aircraft nears terrain. As a result, the pilot unknowingly may place the aircraft in an alert zone conflict or an alert zone conflict watch/warning.

30. *Perceived time pressure/Ownship state*: A pilot under time pressures is more likely to ignore certain aspects of the environment. Therefore, the acceptability of ownship state may suffer (e.g., ownship may be on a collision course).

31. *Perceived time pressure/Accuracy of pilot's current world model:* If a crisis arises and it is not related to self-separation, the pilot obviously will spend relatively less time attending to the traffic-related information. As a result, the out-the-window information regarding traffic or radio communications regarding traffic may be ignored. Therefore, the risk of a separation violation increases.

32. *Perceived time pressure/Accuracy of current machine model*: If a crisis arises and it is not related to self-separation, the pilot obviously will spend relatively less time attending to the CDTI. As a result, the pilot's machine model will be less accurate, and the risk of a separation violation will be more likely.

33. *Perceived time pressure/Appropriateness of planned action*: If the pilot feels pressured by time, the pilot may make decisions too quickly. As a result, the planned action is less likely to be appropriate.

34. *Perceived time pressure/Level of confidence in planned action*: If the pilot feels pressured by time, the pilot may make decisions too quickly. As a result, the pilot may feel less than confident in the action that has been planned.

35. *Perceived time pressure/Level of pilot mental workload*: When a pilot feels the pressures of time, working memory is taxed. As a result, mental workload necessarily increases. If mental workload is too high, the pilot is not able to attend to all relevant stimuli in the environment. Therefore, if the situation that requires attention is not related to self-separation, information regarding the traffic situation may be what is ignored.

36. *Perceived time pressure/Type of action chosen by the pilot*: Although this pair has already been identified as representing a tradeoff, what is of interest here is the influence that perceived time pressure has on the action chosen by the pilot. If the pilot feels pressured by time, the pilot may make decisions too quickly. As a result, the chosen action may be less than satisfactory (i.e., the aircraft may come into an alert zone contact).

37. *Level of pilot mental workload/Ownship state*: These two characteristics were already identified as having a tradeoff relation. What is important here is the effect mental workload has on ownship state. As pilot mental workload increases, the pilot is more likely to ignore some responsibilities. Therefore, as workload increases, it is possible for the acceptability of ownship state to decrease.

38. *Level of pilot mental workload/ Level of air traffic managers' mental workload*: These characteristics have already been identified as having an inverse relation. Specifically, if the pilot performed most of the duties associated with self-separation, the pilot's mental workload would increase in high-density traffic situations. The fewer self-separation responsibilities the pilot performed, the higher the ATM's mental workload would be. These characteristics were also shown to have a direct relation. For example, a pilot under conditions of high mental workload may not respond immediately to an ATM. As a result, the ATM's mental workload may be increased by the pilot's high mental workload.

39. *Level of pilot mental workload/Accuracy of pilot's current world model*: As pilot mental workload increases, the pilot is more likely to ignore some relevant information in the world (e.g., radio communications). Therefore, as workload increases, it is possible that the pilot will have a less accurate "picture" of traffic-related information.

40. *Level of pilot mental workload/Accuracy of current machine model*: As pilot mental workload increases, the pilot is more likely to ignore some relevant information. Therefore, as workload increases, it is possible that the pilot will attend less to the CDTI.

41. *Level of pilot mental workload/Appropriateness of planned action*: As pilot mental workload increases, the pilot is more likely to ignore some relevant information in the world. Therefore, as workload increases, it is possible that the pilot will make hastier decisions and possibly plan a dangerous course of action (e.g., one that leads to a penetration of the alert zone).

42. *Level of pilot mental workload/Level of confidence in planned action*: These characteristics have already been identified as representing a tradeoff relation. However, what is important here is the effect of workload on the pilot's confidence in the planned action. High pilot workload might decrease the pilot's confidence in the planned action. Under high workload conditions, time may not allow the pilot to assess all traffic-related information and leave the pilot feeling less than confident.

43. *Level of pilot mental workload/Type of action chosen by the pilot*: This pairing has already been identified as representing a tradeoff. However, what is of interest are the effects of workload on the type of action chosen. As pilot mental workload increases, the pilot is more likely to overlook relevant information. Therefore, as workload increases, it is possible for the quality of the chosen action to decrease.

44. *General piloting skills/Ownship state*: Because a pilot's experience, ability, and training affect decision making, the state of the ownship (acceptable vs. unacceptable) will, on average, correlate with the pilot's level of skill.

45. *General piloting skills/ Level of air traffic managers' mental workload*: As a pilot's experience, ability, and training increase, the amount of assistance needed by the ATM presumably decreases. Therefore, a pilot with a great amount of skill will lessen the mental workload of the ATM.

46. *General piloting skills/Accuracy of pilot's current world model*: A pilot with a great amount of skill is generally better at knowing when their "picture" of the situation is incomplete. Therefore, a pilot with a great amount of skill will know when to attend to information from the forward field of view or radio communications.

47. *General piloting skills/Accuracy of current machine model*: A pilot with a great amount of skill is generally better at knowing when their "picture" of the situation is incomplete. Therefore, a pilot with a great amount of skill will know when to attend to information on the CDTI.

48. *General piloting skills/Appropriateness of planned action*: A pilot with a great amount of skill is generally more able to predict what will happen in the future. Therefore, the skilled pilot, on the average, will generally plan an action that is more appropriate.

49. *General piloting skills/Level of confidence in planned action*: A pilot with more skill will be more confident in planning their actions. A pilot with less skills will feel less confident in their ability and experience, and as a result, confidence will be relatively lower.

50. *General piloting skills/Level of pilot mental workload*: A pilot with less skill presumable is not able to "chunk" information as well as the more experienced pilot. Therefore, put in the same situation, pilots of different skill levels may experience different amounts of mental workload.

51. *General piloting skills/Type of action chosen by the pilot*: The pilot with greater skills will presumably choose actions that may not be the most desirable, but they achieve the objective and are efficient. The pilot with less skill may, on average, choose a less appropriate action than that of the pilot with great skills.

Table D7. Information Requirements for Traffic Awareness in the Free-Flight Environment

Note: Highlighted information requirements are identical to those presented by either Endsely et al. (1998) or Endsley and Rodgers (1994).

• = knowledge ➢ = information

Pilot:

- **Ownship state**
  - ➢ Identification of ownship
  - ➢ Horizontal position of ownship
  - ➢ Heading of ownship
  - ➢ Speed of ownship
  - ➢ Vertical speed of ownship
  - ➢ Altitude of ownship
  - ➢ Attitude of ownship
  - ➢ Immediate destination of ownship
  - ➢ Route of ownship

- **Future of ownship state**
  - ➢ Future horizontal position of ownship
  - ➢ Future heading of ownship
  - ➢ Future speed of ownship
  - ➢ Future vertical speed of ownship
  - ➢ Future altitude of ownship
  - ➢ Future destination of ownship
  - ➢ Future route of ownship
  - ➢ Future violations of aircraft capabilities (e.g., speed restrictions)

- **Potential for future alert zone contact**
  - ➢ Alert zone contact watch
  - ➢ Alert zone contact warning

- **Ownship planned changes**
  - ➢ Heading changes of ownship
  - ➢ Speed changes of ownship
  - ➢ Altitude changes of ownship
  - ➢ Immediate destination changes of ownship
  - ➢ Route changes of ownship

- **Hypothetical *results* of planned changes**
  - ➢ Hypothetical horizontal position of ownship
  - ➢ Hypothetical heading of ownship
  - ➢ Hypothetical speed of ownship
  - ➢ Hypothetical vertical speed of ownship
  - ➢ Hypothetical altitude of ownship
  - ➢ Hypothetical immediate destination of ownship
  - ➢ Hypothetical route of ownship
  - ➢ Hypothetical violations of aircraft capabilities (e.g., speed restrictions)
  - ➢ Hypothetical alert zone watch
  - ➢ Hypothetical alert zone warning
  - ➢ Hypothetical alert zone contact

- **Other aircraft states**
  - ➢ Id of other aircraft
  - ➢ Horizontal position of other aircraft
  - ➢ Heading of other aircraft
  - ➢ Speed of other aircraft
  - ➢ Vertical speed of other aircraft
  - ➢ Altitude of other aircraft
  - ➢ Immediate destination of other aircraft
  - ➢ Route of other aircraft

- **Future of other aircraft states**
  - ➢ Future horizontal position of other aircraft
  - ➢ Future heading of other aircraft
  - ➢ Future speed of other aircraft
  - ➢ Future vertical speed of other aircraft
  - ➢ Future altitude of other aircraft
  - ➢ Future destination of other aircraft
  - ➢ Future route of other aircraft

- **Number of aircraft nearby**
  - ➢ Number of aircraft that are within a user-specified range of ownship (This range may vary depending on the day, the location, or the situation.)

- **Occurrence of alert zone warning/watch**
  - ➢ Auditory signal of an alert zone warning/watch
  - ➢ Type of alert zone warning/watch (temporary or one that is likely to lead to alert zone contact)

- **Best plan of action to avoid a future or discontinue a current alert zone contact**
  - Optimal changes to horizontal position of ownship
  - Optimal changes to heading of ownship
  - Optimal changes to speed of ownship
  - Optimal changes to vertical speed of ownship
  - Optimal changes to altitude of ownship
  - Optimal changes to destination of ownship
  - Optimal changes to route of ownship
  - Request other pilot to make changes

- **Weather formation existence**
  - Ownship within weather formation (Inform pilot to consult ATM or display outside of system)
  - Ownship headed for weather formation (Inform pilot to consult ATM or display outside of system)

- **Existence of Potentially Dangerous Terrain**
  - Ownship headed for potentially dangerous terrain (Inform pilot to consult ATM or display outside of system)

- **Time frame allowed for ignoring the CDTI**
  - Time until the next alert zone contact watch/warning

- **Current CDTI settings**
  - Current brightness settings
  - Current contrast settings

ATM:

- **Aircraft states**
  - Id of aircraft
  - Horizontal position of aircraft
  - Heading of aircraft
  - Speed of aircraft
  - Vertical speed of aircraft
  - Altitude of aircraft
  - Immediate destination of aircraft
  - Route of aircraft

- **Future of aircraft state**
  - Future horizontal position of aircraft
  - Future heading of aircraft
  - Future speed of aircraft
  - Future vertical speed of aircraft
  - Future altitude of aircraft
  - Future destination of aircraft
  - Future route of aircraft

- **Aircraft Changes**
  - Heading changes of aircraft
  - Speed changes of aircraft
  - Altitude changes of aircraft
  - Immediate destination changes of aircraft
  - Route changes of aircraft

- **Weather formation avoidance**
  - Aircraft within weather formation
  - Aircraft headed for weather formation
  - Optimal changes to altitudes of aircraft
  - Optimal changes to routes of aircraft

- **Terrain avoidance**
  - Aircraft headed for terrain
  - Optimal changes to altitudes of aircraft
  - Optimal changes to routes of aircraft

- **Time frame allowed for working with the present conflict**
  - Time until the next alert zone contact watch/warning
  - Number of aircraft pairs that will have an alert zone contact watch/warning within a user-specified span of time (This range may vary depending on the day, the sector, or the situation.)

- **Potential for future alert zone contact**
  - Alert zone contact watches
  - Alert zone contact warnings

- **Pilots in need of assistance**
  - Aircraft requesting immediate assistance
  - Aircraft requesting long-term assistance