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An Evaluation of RTA Symbols to Improve Pilot Situation Awareness

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AN EVALUATION OF RTA SYMBOLS TO IMPROVE PILOT SITUATION AWARENESS

by

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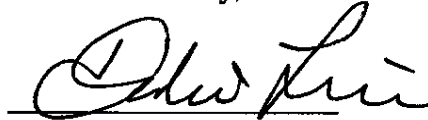Daytona Beach, Florida
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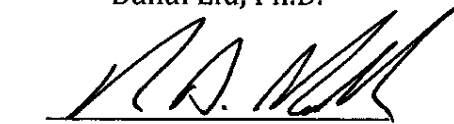
This thesis was prepared under the direction of the candidate's chair, Dr. Shawn Doherty, Ph.D., Department of Human Factors & Systems, and has been approved by members of the thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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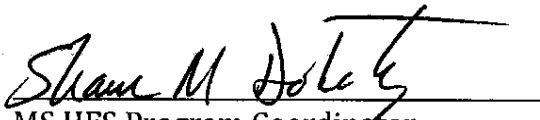
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Abstract

The purpose of this study was to evaluate different types of temporal guidance symbol sets in 4-Dimensional displays. Different displays were evaluated using situation awareness (SA) as a dependent measure. Participants were a mixture of non-pilots and pilots with an average flight time of 155 hours. All 24 participants were randomly assigned to their experimental condition. Objective SA data was collected during the experiment. After the experiment, each participant completed a subjective questionnaire. No significance was found between the pilots and non-pilots. No significance was found between types of displays. And, no interaction was found between groups.

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List of Abbreviations

4D	4-Dimensional
AFAS	Aircraft in the Future ATM Systems
ANP	Actual Navigation Performance
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ASAS	Automated Separation Assistance System
CDA	Continuous Descent Approach
CD&R	Conflict Detection and Resolution
CPDLC	Controller Pilot Data Link
CTAS	Center TRACON Automation System
DataComm	Data Communications
DST	Decision Support Tools
ETA	Estimated Time of Arrival
FMS	Flight Management System
MCDU	Multifunction Control Display Unit
NAS	National Airspace System
NASA	National Aeronautical and Space Administration
NextGen	Next Generation of Air Traffic Control
RNP	Required Navigational Performance
RTA	Required Time of Arrival
SAGAT	Situation Awareness Global Assessment Tool
TBO	Trajectory Based Operations
UAV	Unmanned Aerial Vehicle

Introduction

By recent estimates, the demand for air travel will increase beyond the point that the current air travel infrastructure can handle by the year 2025 (Federal Aviation Administration, 2006). This will create performance implications for both pilots and air traffic controllers (ATCOs) who are attempting to provide a greater level of efficiency of operations under the increased demand while still maintaining the high level of safety that has been the hallmark of U.S. air operations for years. In order to accomplish this feat, one focus of the Next Generation of Air Travel (NextGen) is to find methods to assist controllers and pilots through technology assistance such as Decision Support Tools (DSTs), data communications (DataComm), and 4-Dimensional (4D) displays. New procedures are being developed for the implementation of Trajectory-Based Operations (TBO) where aircraft separation is guaranteed not only in its current location in space, but also in time along its entire flight plan. It is expected that these innovative technologies and procedures will increase efficiency, safety, and the capacity of the National Airspace System (NAS) and also decrease controller and pilot workload.

Due to the performance limitations of ATCOs, they are only able to provide separation assurance for a limited amount of air traffic at any given time. For this reason, the number of aircraft allowed in a particular controller's airspace is limited for safety reasons (Prevot, Homola, & Mercer, 2008a). Trajectory-based operations add a high degree of automation to assist the controller in order to provide safe separation, and to decrease controller workload. The current system of Air Traffic Management (ATM) uses a tactical-type, or clearance-based, system to individually

direct each aircraft. Since air traffic is expected to increase by 150 to 250 percent over the next two decades, controllers will soon be overwhelmed if they are not provided with the tools necessary to more efficiently and effectively manage the growing number of aircraft flying (Prevot, Homola, & Mercer, 2008a). Strategic automation provides real-time rapid-update 4D trajectory prediction, conflict detection and resolution to identify the most efficient and economic trajectories that are conflict free, meet time-based requirements, and avoid convective weather where possible (Prevot, 2009).

However, these mechanisms are not without their issues. It is not feasible to switch to complete TBO overnight, so the NAS must be prepared to integrate aircraft separation automation, DataComm, TBO, and 4D displays slowly, and to account for the fact that not all aircraft operating will be equipped for trajectory-based clearances. Required time of arrival (RTA) is the ability of a pilot to self-deliver to a specific waypoint at a specific time (Ostwald, 2007). Instead of aircraft continuously updating current position and performance information, it will be the responsibility of the aircraft to meet the RTA at waypoints and runway thresholds. The meeting of RTA time constraints will be the fourth dimension in the TBO environment (Prevot, 2009).

Overview of Trajectory-Based Operations

The current method of providing safe separation to aircraft uses the tactical method of diverting aircraft away from one another as conflicts between flights arise. As the amount of air traffic continues to increase, the demand on ATCOs will eventually exceed their ability. Trajectory-based operations (TBO) will utilize a

strategic method for providing aircraft separation, where each aircraft is no longer constrained to only lateral and vertical navigational tolerances, but also longitudinal navigational tolerances. A more efficient flow of air traffic will be achieved through the use of ground-based automation of trajectories and decision support tools will assist with aircraft deconfliction. Route modifications, clearances for the departure, cruise, and approach phase will be communicated to the pilots via DataComm. By issuing clearances through DataComm, verbal communications will become secondary (Smith, et al., n.d.). TBO will allow for user-preferred clearances, such as continuous descent approaches (CDAs), which reduce aircraft maneuvering, controller workload, noise pollution, and increase fuel efficiency (Penhallegon, & Bone, 2008). Pilots will require a 4D display that incorporates temporal guidance information at the primary level, as opposed to requiring multiple keystrokes to access RTA information (as with current RTA use). This temporal information needs to be presented to the pilot in a way that is intuitive and maximizes situation awareness (SA), which is vital for increasing overall pilot/system performance (Endsley, 1988).

Ground-Based Automation

Ground-based automation that produces 4D trajectories is a key component of the TBO operational context. Studies have shown that ground-based automation increases efficiency, improves safety, and reduces controller workload by producing conflict free trajectories in conjunction with DSTs for conflict detection and resolution (CD&R)(Mueller, 2007). Under this method of aircraft separation, there would be two layers of separation assurance. The first is the strategic method of

aircraft separation. Trajectories are conflict free not only in their current position in space and time, but along the entire flight path. The second layer exists to ensure aircraft separation by giving the controller the ability to tactically separate aircraft if the need arises (Prevot, Homola, Mercer, 2008a). While trajectories are produced by a ground-based automation system, data communication (DataComm) will be used to send those trajectories to the aircraft, where they can then be uploaded into the flight management system (FMS).

Data Communications

Over time DataComm will eventually surpass voice as the primary means for communication between ATCO and aircraft (Smith, et al., n.d.). A number of studies have been done to test pilot acceptance and the usability of DataComm. Overwhelmingly the literature suggests that pilots have no problems using DataComm, prefer it to traditional voice communications, and do not feel it unduly affects performance (Funabiki, 2004; Mueller, 2007).

Mueller (2007) showed that DataComm is capable of communicating both vertical and horizontal strategic trajectory route modifications. When an alternate route was presented to the pilot through DataComm, the pilot saw a graphical display allowing him to assess the trajectory in order to better accept or reject it. A laboratory simulation was conducted where a human controller generated conflict resolution trajectories using an automated trial planning system (Mcnally & Gong, 2006). When a conflict arose, the controller would issue resolution trajectories via DataComm. The planning resolution function increased the efficiency of the controller, and allowed them to manage a workload typically handled by 5-10

controllers. Once the trajectory is communicated to the aircraft, it is then the responsibility of the pilots to adhere to the temporal constraints inherent in TBO.

Temporal Guidance

In order to maximize the temporal performance of pilots, temporal information needs to be presented in such a way that is intuitive and increases (or at least does not decrease) pilot situation awareness. Temporal constraints will meter the arrival rates of aircraft, leading to a greater throughput at the runway threshold and trajectories that are conflict free. There are three methods for controlling the temporal performance of aircraft (Ballin, Williams, Allen, & Palmer, 2008).

Continuous Guidance Control. The first method for controlling time-based guidance is using continuous guidance control throughout the flight. The aircraft is continuously updating its position and performance information to the NAS. Aircraft performance would also be continuously adjusted in order to meet minimum and maximum allowable arrival tolerances. One potential negative for this method is that the constant adjustments in speed will not be as fuel-efficient as the RTA method of time controlled guidance. When the guidance control is continuously updated and varying performance in order meet the object, this can lead to an excessive number of corrections by the FMS ("chasing the needle"). The excessive corrections leads to unnecessary fuel burn (Ballin, Williams, Allen, & Palmer, 2008).

Airborne Separation Assistance System. A second option for increasing NAS efficiency is the Airborne Separation Assistance System (ASAS). Prevot,

Battiste, Everett, and Stephen (2003) propose combining strategic, 4D user preferred trajectories with the tactical ASAS. The purpose of ASAS is to increase the situation awareness of pilots and decrease the workload of controllers. ASAS accomplishes this by delegating some aircraft separation responsibilities to the pilot. Barmore (2006), through an in depth review of studies done from 1999-2006, also recommends that pilot controlled spacing is feasible and can greatly reduce controller workload while increasing runway throughput.

Prevot, Paul, Callantine, Smith, and Palmer (2003) also suggest that relative aircraft-to-aircraft spacing techniques show potential, and solve many of the issues—such as trajectory prediction accuracy—that arise with using a pure TBO approach to aircraft spacing.   However, for aircraft to utilize ASAS, new hardware would need to be installed in all aircraft that wish to participate.

RTA Predictive Guidance. The third method for providing temporal guidance to aircraft is by requiring aircraft to meet specific waypoints at specific times along their flight plan. Required time of arrival (RTA) is preferable to the previously mentioned systems because the current generation of FMSs can meet RTA requirements (Wichman, Carlsson, & Lindberg, 2001). RTA has also been shown to be more forgiving of weather forecast errors and is more fuel efficient (Ballin, Williams, Allen, & Palmer, 2008), because it periodically (as opposed to continuously) updates performance information.

Required Time of Arrival

Required time of arrival (RTA) is the ability to guide the aircraft to a particular waypoint at a specific time. Each aircraft would have a series of RTAs

built into their flight plan, with one accompanying each waypoint. Aircraft operating under these circumstances must be equipped with a 4D display to communicate to the pilot what their estimated time of arrival (ETA) and RTA are. The pilot then seeks to control the aircraft so that this RTA error is within minimum tolerances for temporal performance. Ideally, so long as the aircraft is meeting its RTA, separation assurance will be guaranteed along the entire flight path. In practice, the onboard FMS will control aircraft performance through "auto-throttle", optimizing fuel efficiency and meeting the RTA within a few seconds. The FMS will also have to periodically update the projected ETA and make necessary adjustments to arrive within the allowable arrival tolerance. Ballin, Williams, Allen, and Palmer (2008) recommend the FMS update its status approximately every 15 seconds.

One benefit to trajectory-based clearances is that it enables the use of user-preferred trajectories, such as continuous decent approaches and wind favorable routes. Fuel-efficient descents will automatically be incorporated into the trajectories provided to pilots. Automated wind route analysis has been successfully used in Fort Worth Center Airspace and has been proven to effectively increase the efficiency of aircraft flying. An estimated $200M a year can be saved without adversely affecting the distribution of ATCOs (McNally, et al., 2010).

RTA exists in many commercial aircraft; however it is generally considered an ancillary function in the FMS. Because it is ancillary, it generally involves an excessive amount of keystrokes or steps to access the function. If RTA were to become an integral part of TBO, it would need to be made a primary function within the FMS. RTA is also displayed in manner that is not intuitive to pilots. The

information is currently displayed as raw data as shown in Figure 1, when a

graphical or general "ahead of", or "behind of" would be of better use to pilots

(DeSmedt, & Berz, 2007).

Figure 1. The above display is an example of a current method for showing RTA

error. On the top right of the screen it shows the RTA, ETA, and RTA error. At the

top of the screen it also shows the distance to the next waypoint and gives the call

sign of the waypoint. Adapted from "Study of the Required Time of Arrival Function

of Current FMS in an ATM Context," by D. DeSmedt and G. Berz, 2007, *IEEE*.

A study done by Haraldsdottir, Scharl, King, Schoemig, and Berge (2008)

consisted of an analysis of an RTA function that has speed control in both cruise and

descent. The study showed that RTA could clearly deliver aircraft accurately to a

specific point in time. The study did a comparison between 3D and 4D concepts in a

realistic scenario. The 4D scenario delivery of aircraft was 81% more accurate than

the current tactical method of aircraft control. RTA is a key part of TBO, especially

in the arrival phase of flight, in order to maximize runway throughput. It is

dependent on expected advances in ATC automation.

Required performance and actual performance need to be discussed because it is possible an aircraft may be given a required time of arrival where the actual navigation performance of the aircraft is insufficient. The temporal performance of an aircraft can be discussed in two terms: Required Navigational Performance (RNP), and Actual Navigational Performance (ANP) (Ballin, Williams, Allen, & Palmer, 2008). RNP is the performance measure that an aircraft must meet in order to meet an RTA. ANP is the actual temporal performance of an aircraft. The addition of a temporal performance measure to navigational minimums means that aircraft are no longer only concerned with the lateral component of navigation (staying on a flight path) but also the longitudinal component (along the flight path). Ballin, et al. established different tolerances for different legs of a flight: 120 seconds for cruise; 30 seconds for arrival; and 15 seconds for approach.

In some cases an aircraft may not have the performance necessary to make an RTA. In this situation Ballin, Williams, Allen, and Palmer (2008) recommend RTA relaxation so an aircraft does not inadvertently violate their RTA. An RTA is relaxed by broadening the arrival tolerances at a specific waypoint. Ballin, et al., with the purpose of implementing RNP/ANP concepts, and to test RTA relaxation, developed a prototype 4D interface. Two main elements were evaluated: the symbol set to display temporal RNP/ANP; and, incorporation of RNP progress information into a Multifunction Control Display Unit (MCDU). During the simulation several waypoints had RTAs assigned. Participants were required to fly the simulation and meet the RTA. RTA relaxation was tested by having one RTA one minute beyond the performance capabilities of the aircraft. The prototype was able to accurately relax

RTA constraints when necessary; display the RNP/ANP symbols; and incorporate the RNP/ANP information with the MCDU. The literature suggests that RTA predictive guidance is more forgiving and flexible than the other methods of temporal guidance. Studies have shown that RTAs can be relaxed if it exceeds the performance capabilities of the aircraft (Ballin, Williams, Allen, and Palmer 2008); ATCO can switch to tactical separation methods if necessary (Prevot, Homola, Mercer, 2008a); and, lateral offsets from the trajectory have also been successfully tested if the need arises to move an aircraft off trajectory (Ostwald, 2007).

Integrating Trajectory-Based Operations

TBO can be applied in the 2012 time frame using existing technology. McNally, et al. (2010) propose a TBO system that can start to be tested using current DataComm technology. Their lab simulation showed the integrated operation of several components of TBO: strategic automation, fuel-efficient descents, wind-favorable routes, weather avoidance, conflict detection, conflict resolution, controller interface, DataComm, and tactical automation (back-up).

Studies done on the level of automation showed that controllers readily accepted the usage of highly automated separation of aircraft (Prevot, Homola, & Mercer, 2008b). Prevot (2009) also suggests that automation can greatly increase the efficiency of controllers, allowing them to handle more aircraft at a given time. The technology is readily available, and a smooth integration of technologies can be done safely (Teutsch, & Hoffman, 2004). However, an investigation of the impact that 4D displays will have on situation awareness is not present in today's literature.

Justification for RTA Symbol Set

The symbols decided upon for this study are derived from FAA Human

Factors Design Standards, literature on RTA procedures and automated airborne

temporal spacing symbol sets. A pilot requires the following information in order to

execute RTA operations: position error indicator, time error indicator, RTA, ETA,

current performance, required performance, and conflicting aircraft intent

information (Cheng, Andre, & Foyle, 2009). These information requirements should

be presented in a manner consistent with the FAA best practices for aviation

displays (Ahlstrom, & Longo 2003).

There are three methods that can be used to show RTA in the cockpit. One

method is a text based symbol set to show RTA, ETA, and RTA error, shown

previously in Figure 4. This is in use in today's ancillary RTA function, but has been

described as unintuitive by pilots (DeSmedt, & Berz, 2007). Another method to

show RTA is a graphic based symbol set. However, a pure graphical symbol set with

no quantitative values is not present in today's literature. Likely, because a purely

graphical display approach would not be specific enough and may lead to errors.

The third method is a combination of graphic and text based symbol sets. The most

common symbol set is a timeline of sorts, potentially with numerical values giving

the timeline scale. Juxtaposed with the timeline are quantitative values of the RTA,

ETA, and RTA error to show precise values (which is necessary because RTA is a

precise operation). One example of a timeline is shown in Figure 2. This display is a

mix of quantitative and qualitative symbols to both give the pilot a general notion of

their temporal performance at a glance, and also to give precision information if necessary.

(a) Active guidance mode.

(b) Provisional guidance mode.
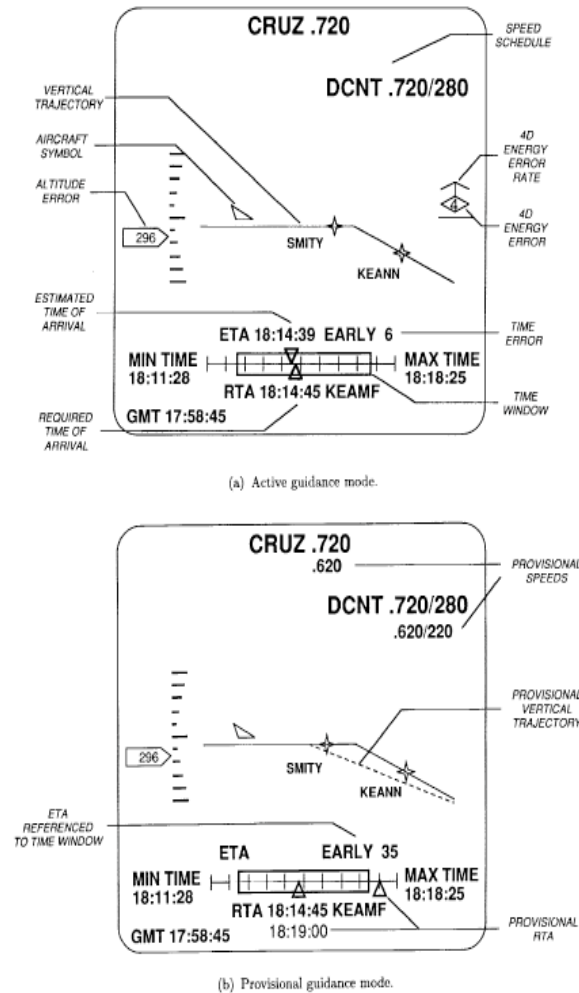
Figure 2. The above is a mixed quantitative and qualitative symbol set for RTA guidance. The timeline for the top figure shows the RTA as a triangle fixed on the timeline, with the RTA numerical value underneath. The ETA is a sliding triangle on the timeline, with the numerical value above. The difference between the triangles is the RTA error, which is also shown textually as "EARLY 6" (6 seconds early). Adapted from "Airborne Four-Dimensional Flight Management in a Time Based Air

Traffic Control Environment", by D. Williams and S. Green, 1991, *NASA Technical Memorandum 4249.*

A large portion of the display in Figure 2 is dedicated to conveying 3 pieces of information: RTA, ETA, and RTA error. Cheng, Andre, and Foyle (2009) have shown another symbol set that also uses a mix of qualitative and quantitative symbols for RTA operations on the airport surface, as shown in Figure 3.
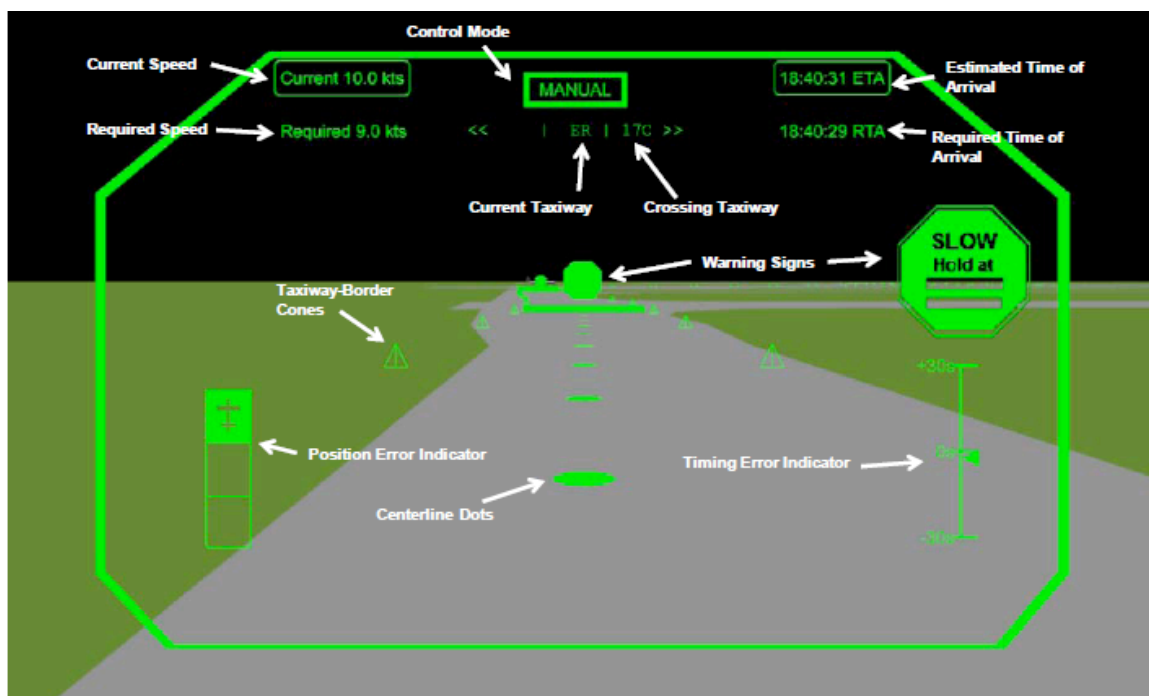
Figure 3. RTA symbol set used on the airport surface. On the left is a position error indicator, designed to give the pilot fast way to determine if he is ahead, behind, or on position. Time error is shown on the right as a time bar, with the negative being the bottom half, and the positive being the upper half. Exact RTA and ETA values are shown in the upper right. However, the critical precision information—RTA error—is not shown quantitatively. Adapted from "Information Requirements for

Pilots to Execute 4D Trajectories on the Airport Surface", by V. Cheng, A. Andre, D.

Foyle, 2009, *9th AIAA Aviation Technology, Integration, and Operations Conference.*

While the display shows quantitative and qualitative information without

being overbearing, it lacks precise RTA error information. The pilot is required to

either interpret RTA error from the time bar, or by doing the mental calculation to

find the difference between the RTA and ETA. Because there isn't any literature

investigating the benefits to having a graphical display, it is unclear if the pilot

actually gains anything from the time bar. The position error indicator is also

somewhat weak because it lacks gradual movement: one is either on target, early or

late. A better position indicator would have gradations of position error.

One symbol set that was developed for automated airborne temporal spacing

combines the best elements of the above displays, while omitting extraneous clutter.

Figure 4 below shows a time box method used in a study by Prevot, et al., (2004).

Figure 4. Automated airborne temporal spacing tool. The above figure includes a

sliding time box to qualitatively show if the aircraft is spaced properly from the
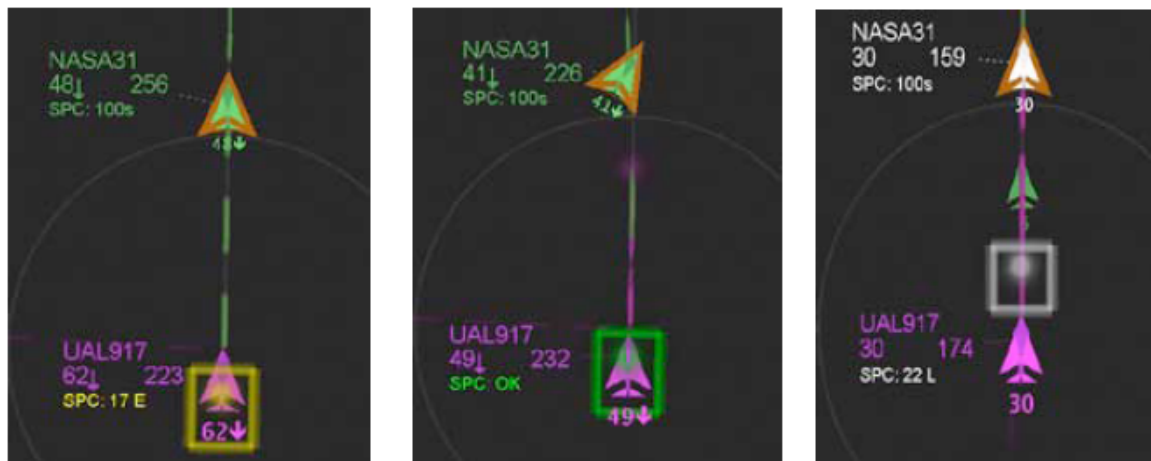
aircraft it is following. It also shows specific quantitative spacing information to the left of the time box. When spacing is within limitations the qualitative and quantitative information is shown in green; when early they change to yellow; when late it turns to white. Adapted from "Trajectory-Oriented Operation with Limited Delegation: An Evolutionary Path to NAS Modernization", by T. Prevot, et al., 2004, *AIAA 4th Aviation Technology Integration and Operations (ATIO) Forum.*

The above display satisfies the information requirements put forward by Cheng, Andre, and Foyle (2009), meets FAA human factors design standards, and shows both qualitative and quantitative temporal guidance information. Because this method of aircraft spacing is based on temporal performance, this display can be easily modified to work with RTA waypoints. An example display developed for this study is shown in Figure 5. However, it is still unknown if the qualitative information (the time box) will increase situation awareness significantly beyond the SA achieved with only qualitative information shown in an intuitive manner.

Situation Awareness and Aviation

Even an expert decision maker will make bad decisions using poor information. For this reason, a thorough understanding of one's environment in a dynamic system is critical for decision makers to be successful. For the purpose of this study SA will be defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995b). Based on this

definition, SA can be broken into three levels: perception of the elements in the environment; comprehension of the environment; and projection into the future.

While it is widely established that RTA increases runway throughput, general efficiency, can be implemented in the near term, and is accepted by pilots (McNally, et al., 2010; Prevot, Homola, & Mercer, 2008b; Prevot, 2009; Teutsch, & Hoffman, 2004), a study on the effect RTA symbol sets have on SA has yet to be completed. Since RTA will be used in the near term of NextGen, it is necessary to evaluate the effect RTA symbol sets have on SA. To effectively evaluate situation awareness, one must choose an appropriate measure.

Measures of Situation Awareness

Situation awareness is not simply the comprehension of a specific moment, but is developed over time as a person builds a mental model of their environment. The Situation Awareness Global Assessment Tool (SAGAT) was designed to interrupt an ongoing simulation or process to objectively evaluate the participant's SA randomly over the duration of a study (Endsley, 1995b). This study was limited because simulation capability was not available. Because the study only showed screenshots of a display, a growing and well-developed mental model was not built by the participants.

To prevent the participants from focusing on only one piece of information, thus having an incomplete understanding of the environment, two types of hazard information were incorporated into the display. Participants had to assess hazardous weather and potential conflicts with other aircraft.

While the SAGAT method is capable of evaluating SA up to the third level (projection into the future), this study evaluated the first two levels of SA: perception and comprehension. Participants were asked general questions about the navigation displays, test both perception and comprehension. For example, participants were asked about their longitudinal performance (whether were fast or slow). This is quantitative information, but even if the participants answered the questions accurately they still may not comprehend the meaning of the information. However, to accurately answer a qualitative question about hazard information, or position error required comprehension of the display. Because the time box is a qualitative symbol, it required comprehension in order to be interpreted accurately. In theory, participants who accurately answered position error questions achieved the second level of SA (comprehension). Since position error can be gleaned from either the quantitative RTA error or the qualitative time box, a statistical comparison of both types of symbols can be made.

Ability Requirements

When a pilot is flying they are performing an egocentric task—they are immersed in their environment. Even when a pilot is flying solely by instruments they still receive feedback from the environment (Hunn, 2005). In this study, pilots were simply be looking at a display, attempting to perceive and comprehend the information on said display. This is an exocentric task and is more akin to the work of ATCO and unmanned aerial vehicle (UAV) operators. What is unknown is if a particular skill set will make one group (pilot vs. non-pilot) perform better under a particular experimental condition.

Carretta (1993) found that some of the primary abilities looked for in fighter pilots are situation awareness, time-sharing, selective attention, divided attention, and perceptual speed (some desired abilities were omitted here because not all traits desirable in fighter pilots are generalizable to commercial or general aviation, i.e., aggressiveness). The display in this experiment was designed to be simple enough to require minimum training and little or no inherent ability. However, it is possible that the nature of the display will be so alien to non-pilots they may not be able to discriminate between important and unimportant information. If there is a difference in performance between pilots and non-pilots it may be due to pilots having the requisite abilities listed above.

Due to the exocentric nature of the experiment, some other abilities may affect the outcome of the experiment. EiBfelt, Heil, and Broach (2002) found that the more desirable abilities for ATCOs in the future ATM system are "Speed of Closure", and "Visualization". Speed of closure refers to the ability to quickly organize information into meaningful chunks. Visualization refers to the ability to imagine spatial relationships. Both of these abilities are necessary in, but not exclusive to pilots.

While the abilities of the participants are important to consider, the display was simple enough to where no significant difference in performance was expected between pilots and non-pilots. However, data was unavailable to support the argument that there will not be a difference, as data on non-significant results are typically not published. Even though this study hypothesized there will be no

difference it was still necessary to empirically test and to evaluate the effectiveness of the displays.

Summary

TBO is a proposed solution to the problem of ever increasing air traffic congestion. It is absolutely necessary that the NAS be upgraded to increase efficiency without compromising the FAA's stellar safety record. This will likely be accomplished through ground based automation that will generate conflict free trajectories to aircraft via DataComm. Since TBO is concerned not only with the lateral portion of the flight plan, but also the longitudinal, temporal information needs to be conveyed to the pilot. This will be done on a 4D display that will communicate RTA, ETA, and RTA error quantitatively. This information needs to be shown in a manner that is intuitive, but it is unknown if the information should also be shown qualitatively. It is also unknown if the addition of qualitative symbols, such as a time box, will actually add value to pilot situation awareness. The purpose of this research was to explore potential methods for displaying RTA information on a navigation display in order to improve SA.

Statement Hypothesis

Hypothesis 1: There will be a difference between types of displays in terms of situation awareness.

Hypothesis 2: There will be a difference between types of displays in terms of preference.

Hypothesis 3: There will be no significant difference between pilots and non-pilots in terms of the situation awareness.

Hypothesis 4: There will be no difference between pilots and non-pilots in terms of preference.

Hypothesis 5: There will not be a difference between pilots and non-pilots and types of displays in terms of situation awareness.

Hypothesis 6: There will not be a difference between pilots/non-pilots and type of display in terms of preference.

Method

Participants

Twenty-four participants were randomly selected from Embry-Riddle Aeronautical University in Daytona Beach, FL to participate in the study. The participants were separated into two groups: 12 pilots and 12 non-pilots. All participants were selected to participate on a volunteer basis. Among pilots, average flight time among pilots 150 hours. Participants were asked to sign a consent form acknowledging their willingness to participate. The first, second, and third place performers in each group were awarded $100, $50, and $25 respectively.

Apparatus

The study was conducted on a PC based computer system with a keyboard and mouse. Power Point was used to build custom navigation displays to convey RTA information. Each screenshot had a predetermined inquiry on the next

following slide. Participants answered all questions on an answer sheet (Appendix A).

RTA information was shown in three different symbol sets. One representation was a text based symbol set. RTA error was shown as a numerical value next to the waypoint, as shown in Figure 5.
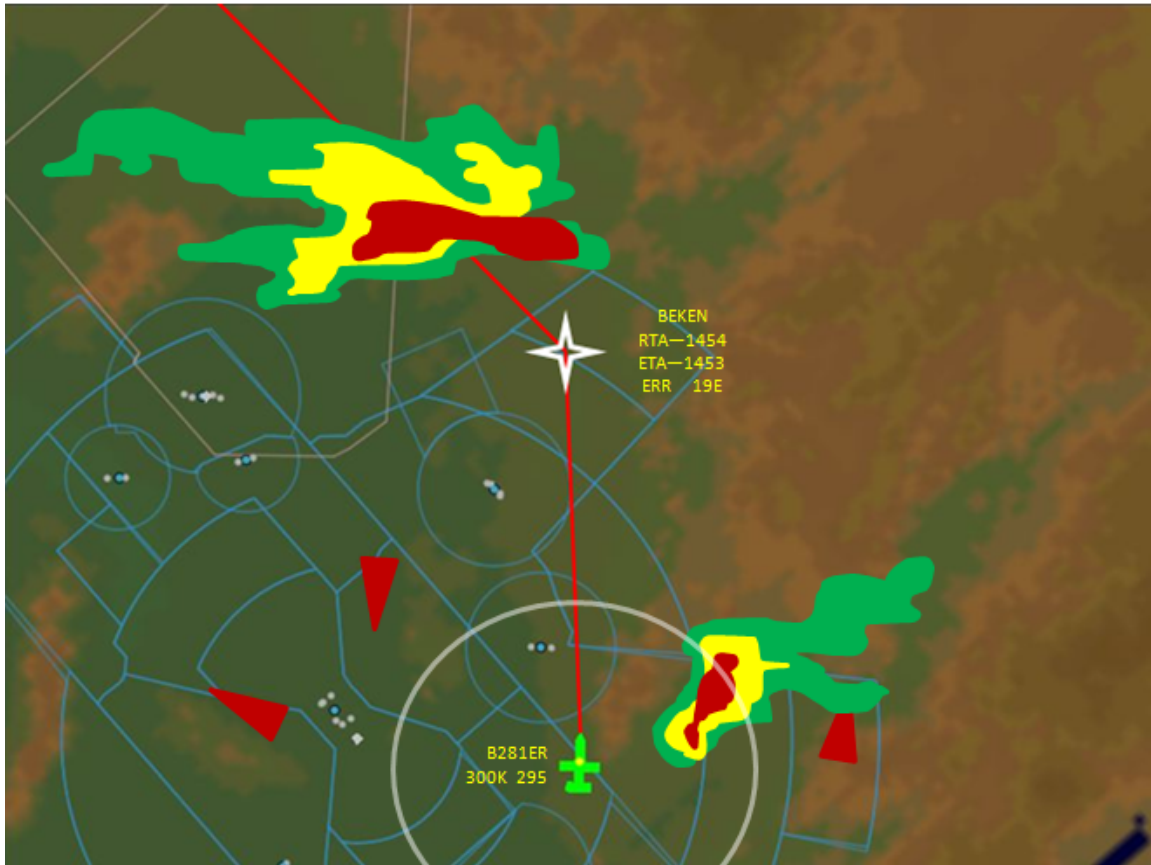
Figure 5. Experimental display showing RTA error as textual information. The waypoint is shown as a star with the flight path being represented by a red line. The aircraft call sign, airspeed, and heading are shown to the left of the aircraft icon. The waypoint call sign, RTA, ETA, and RTA error are shown to the right of the waypoint.

Another RTA symbol set was shown as a graphic based display. RTA was represented in the form of a time box as shown in Figure 6. When the time box was forward of the aircraft icon, the participant was late. When the time box was aft of the aircraft icon the participant was early. The time box was also color coded to show the aircraft as early (blue), late (magenta). Participants had a two-minute window to meet their RTA (one minute early to one minute late). The time box also showed the gradations of their position error. If the participant was 60 seconds early, they were about to exceed the allowable arrival window (60 seconds on both sides of the RTA).
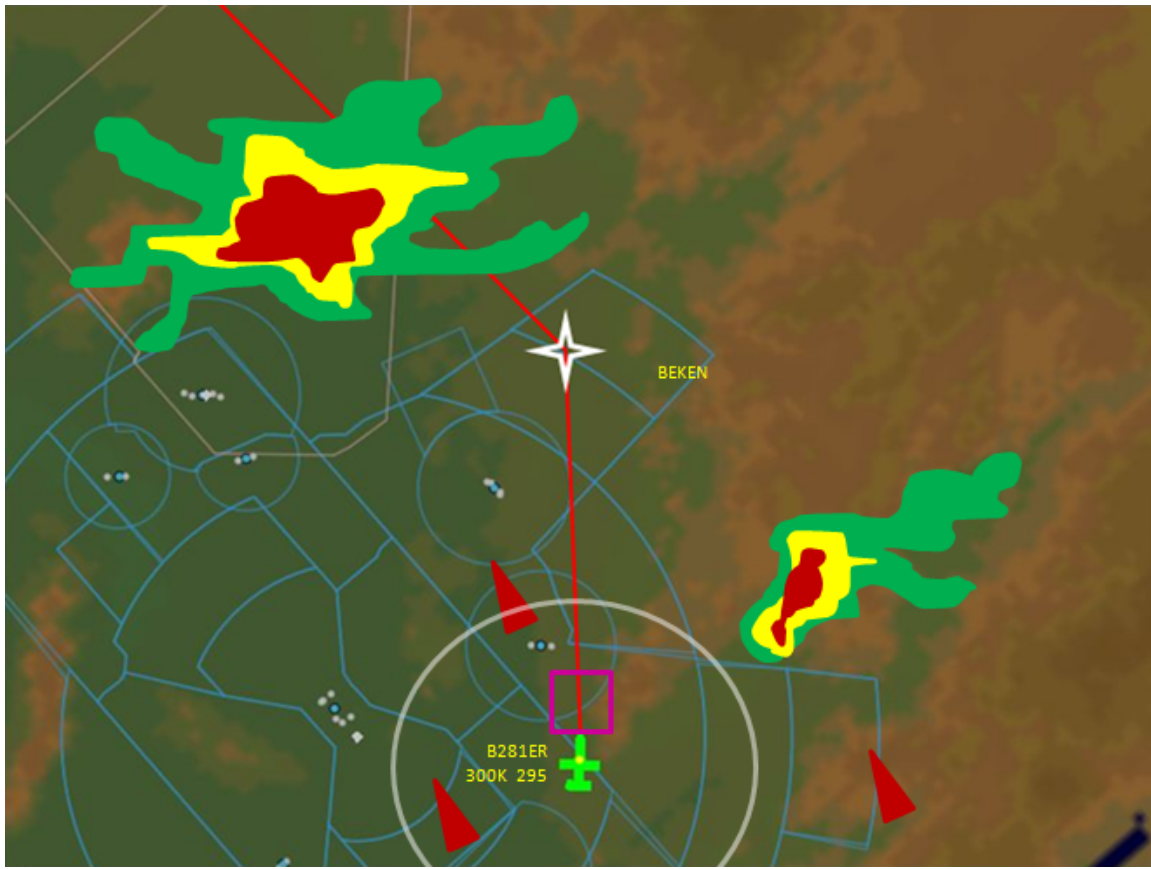
Figure 6. Experimental display showing the graphic symbol set. Symbol set consists of a time box that moves aft and turns blue when the aircraft is fast. When the aircraft is slow the time box moves forward and turns magenta. The time box overlays the aircraft icon. The above aircraft has an ETA greater than 60 seconds prior to the RTA.

The final method for displaying RTA error consisted of a mixture of graphical and textual symbols. The graphical portion of the symbol set consisted of a time box located around the aircraft icon as shown in Figure 7. The time box functioned identically to the condition mentioned above in the "graphical" condition.
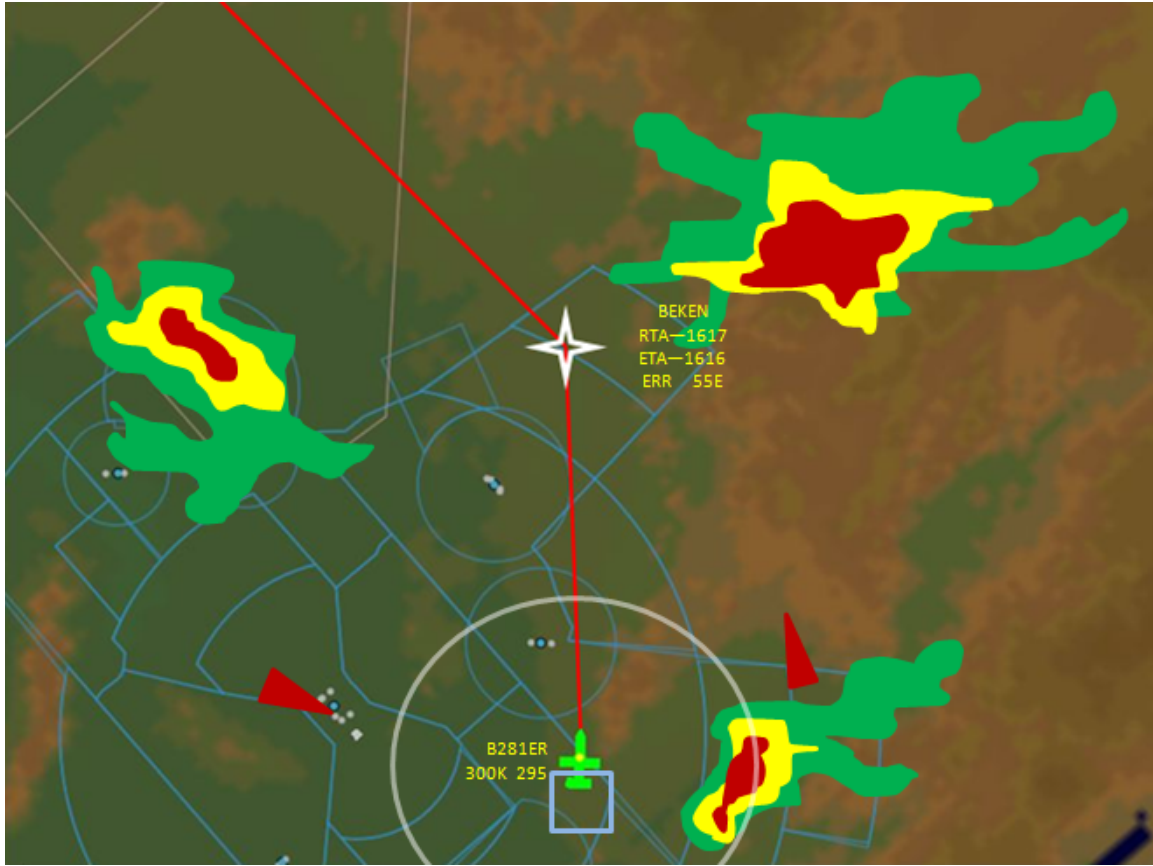
Figure 7. Experimental display showing the mixed numerical and graphical

representation of RTA error. The waypoint call sign is to the right of the waypoint,

while RTA, ETA, and RTA error are shown to the right of the aircraft icon. The time

box over the aircraft icon moves forward and aft and changes from blue (early), to

magenta (late). The aircraft in this display is still within its time window, because a

portion of it is still within the time box.

Design

A 2x3 mixed between-, and within-subjects, fully factorial design was used in

the study. The first independent variable (IV) was skill with two levels: pilot and

non-pilot (between subjects). The second IV was display type with three levels: text

display, graphic display, and a mixture of text and graphic (within subjects). There

were two dependent variables (DVs). One was an objective evaluation of SA. Data was collected in the form of a survey where the accuracy of the participant's perception and comprehension of each display was measured. The second was a subjective evaluation of the displays, where participants were asked if any particular display was favorable after all 3 conditions were experienced.

Tasks

There was a primary and secondary task each participant completed. Each participant viewed a series of non-interactive navigation displays. The non-manipulated information shown on the display was identical for each screenshot for all participants, consisting of terrain and water (shown as flat green/brown and blue), and airspace markings. The non-manipulated portion of the display was taken from a prototype 4D display developed at the NEAR lab at Embry-Riddle Aeronautical University, Daytona Beach, Florida. An aircraft icon was at the bottom center of the display and represented the participant's aircraft. Potential aircraft and convective weather conflicts represented hazard information. All weather was convective, but was not necessarily a threat. Similarly, not all aircraft shown represented a conflict. The participants were instructed that for a hazard to represent a conflict it needed to be within the hazard ring, as shown in Figure 8. The participants were responsible for determining if a hazard existed, and answered questions about temporal performance. All participants were given instruction on what was considered a hazard. An example display is shown in Figure 8.
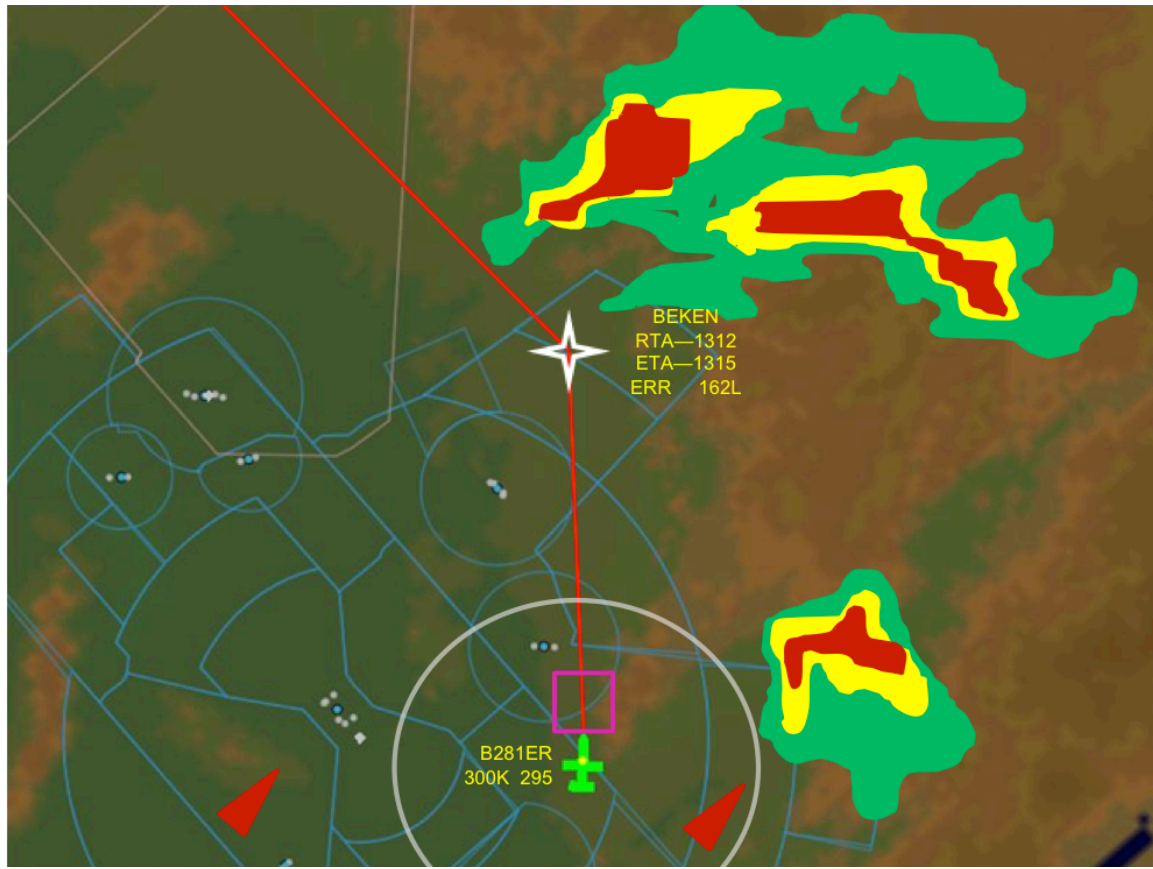
Figure 8. Sample display showing potential hazards. Weather is shown as a green cloud, yellow, and red, where red signifies convective weather. Other aircraft are shown as a triangle with aircraft intent information to the left of the icon. The aircraft within the 5 nm hazard ring is considered a hazard. The weather does not penetrate the 5 nm hazard ring and therefore is not considered a hazard.

Primary Task. The primary task for each participant was to determine what his or her ETA was relative to his or her RTA. Each participant was shown a series of slides consisting of non-interactive screenshots of a navigational display. Each slide was visible for four seconds. After each screenshot there was a slide containing a question, taken from the SAGAT survey, which the participant

answered on an answer sheet (Appendix A). There were 50 slides per condition, with 150 slides total. Slides were presented in a random order (within a particular display condition), each with a pre-assigned question from the SAGAT questionnaire.   If an RTA error was present, the participant needed to supply the type of error (early or late). The accuracy of the participant's responses were measured.

Secondary Task. The secondary task was to determine if a given trajectory was hazard free. The purpose of the secondary task was to keep the participant from focusing only on performance information. This also required the participant to have comprehension of the flight display, i.e., the second level of situation awareness.   Hazards were randomly distributed among the slides. Even if a hazard was present, the SA question they were asked may not have been inquiring about the hazard. Participants were instructed that for a conflict to be considered a hazard it had to be located within the 5 nm hazard ring. They were not be required to predict movement of weather or other aircraft.

Objective Situation Awareness

Objective SA will be evaluated using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988). While the purpose of this study is to recommend a symbol set for representing RTA error, that alone is not enough to properly assess SA. SA is concerned with not only one data point, but rather with a persons' complete understanding of their environment. The researcher attempted to force the participants to have a general understanding of their environment by

requiring them to answer questions unrelated to RTA error. This kept the participants from focusing on only one part of the display. However, due to the nature of the experiment, a holistic picture of the environment could not be formed. Therefore, projection into the future was not assessed. For that reason, the study only evaluated the participants up to, and including, level two SA (Ensdley, 1989).

Subjective Measures

Upon completion of the study each participant was asked a series of subjective questions to determine if they had any preferences for any of the display formats. The questionnaire is shown in Appendix B.

Procedure

Each participant was asked to read and sign a consent form upon arrival to the lab (see Appendix C), as well as an experience questionnaire for background information (see Appendix D). The participants were given instructions, in varying sizes of groups, on how to interpret the display read from a script (Appendix E). The participants did not begin the experiment until they had a clear understanding of the symbols on the display. Any questions the participants had at this time were answered. All participants experienced trial runs of the experiment for all experimental conditions to familiarize themselves with the displays and the type of questions that will be asked. Each participant experienced 3 experimental conditions. Because there were 3 experimental conditions, there were 6 possible permutations a participant could experience the experiment. There were 12 participants in each group so that two individuals could experience each

permutation.   Participants were shown a screenshot of a TBO display for 4 seconds.

After each display slide there was a question slide where the participant was asked

a predetermined question from the SAGAT questionnaire (see Appendix F). The

SAGAT questionnaire acted as a pool of questions to be drawn from. After all

conditions were finished the participants completed a post experiment

questionnaire (see Appendix D). After completing the subjective measure form,

each participant was debriefed (see Appendix E).

Results

A repeated measures ANOVA was conducted to compare two independent

variables (IVs) (Skill and Display Type), on the dependent measure of situation

awareness (SA). The Skill IV had two levels: Pilot and Non-Pilot. There were three

levels of the IV Display Type: Mixed, Graphic, and Text. This study was a mixed

between- and within-subjects, fully factorial experimental design. See Table 1 for

descriptive statistics. Figure 2 shows a graph of the mean scores. There were 24 (N

= 24) participants total, with 12 (n = 12) participants in each group.

Table 1

Descriptive statistics of participant SA scores

Display Type	Skill	*M*	*s*	N
Mixed	Pilot	44.42	4.12	12
	Non-Pilot	42.92	5.84	12
	Total	43.67	5	24
Text	Pilot	44.42	3.4	12
	Non-Pilot	43.08	5.16	12
	Total	43.75	4.33	24
Graphic	Pilot	46.5	3.06	12
	Non-Pilot	43.83	3.13	12
	Total	45.17	3.32	24
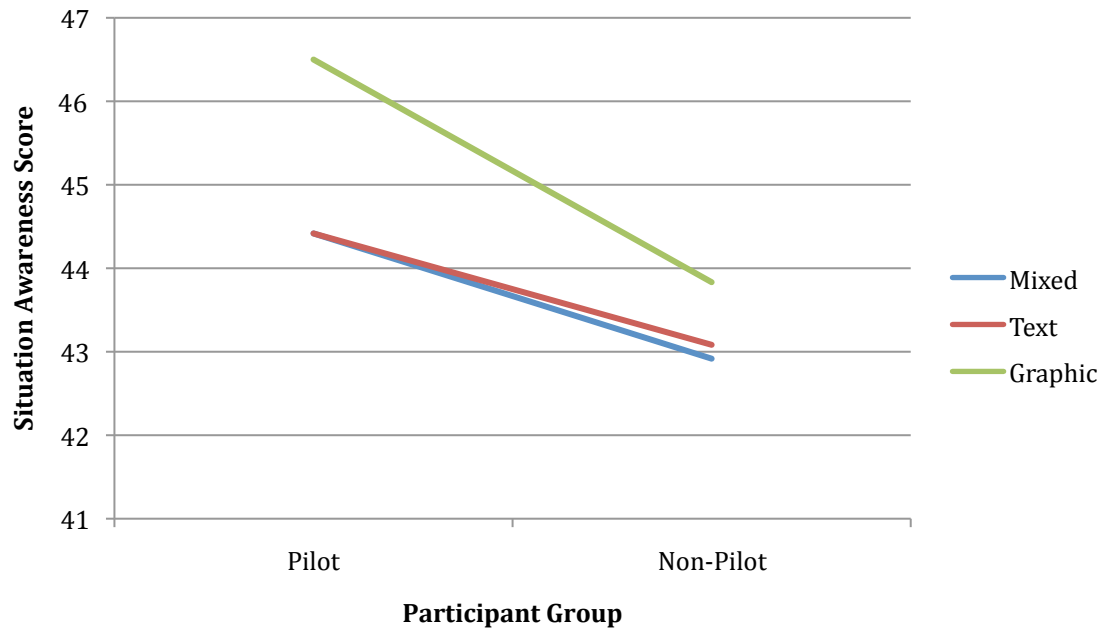
Figure 9. Graph showing the mean scores for pilots and non-pilots. Participants clearly received higher scores using the graphic display than they did using the text or mixed display. Scores are the situation awareness scores the participants received.

The repeated measures ANOVA showed no significance either in the interaction between skill and display type or within the display type, as shown in Table 2. The effect size shows that 5%, 9%, and 1% of the variance was accounted for in the display, skill, and display by skill interaction.

Table 2

Analysis of variance of within- and between-subjects effects on SA scores

Source	SS	df	MS	F	p	Effect Size	Observed Power
Display	34.11	2	17.056	1.274	.29	.055	.262
Skill	60.5	1	60.5	2.206	.152	.091	.295
Display * Skill	6.33	2	3.17	.237	.79	.011	.085
Error	588.889	44	13.384				

Each participant completed a subjective questionnaire after the experiment. Refer to Table 3 for a summary of the preferences of participants.

Table 3

Summary of the post-experiment questionnaire

	Preferred Text	Preferred Mixed	Preferred Graphic
Pilot	33%	17%	50%
Non-Pilot	18%	41%	41%

Discussion

There were three hypothesis statements made for the objective data gathered during the experiment (There will be a significant difference between types of displays in terms of situation awareness; There will be no significant

difference between pilots and non-pilots in terms of the situation awareness; There will not be a difference between pilots and non-pilots and types of displays in terms of situation awareness).

The first hypothesis statement was found to be false because no significant difference was found after completing the repeated measures ANOVA. Participants received higher scores, on average, when using the graphic display than they did on both the text based, and mixed displays. A possible explanation is that when symbols are effectively used they do not require recoding the way the text based symbol would (Sanders, & McCormick, 1993). However, this was statistically insignificant in this case. A possible explanation for why no significance was found is that the questions asked during the experiment simply were not difficult enough. A previous set of questions was pilot tested and were generally much more difficult. However, the questions asked for much more specific information, (e.g. "How far behind schedule are you?"). It was decided that these questions were more of a memory test than an SA evaluation. Therefore, a more basic questionnaire was developed that may have made the experimental task too easy for the participants. The average scores in Table 1 range from about 42 to 45. Since the highest possible score is 50, the participants were approaching a ceiling effect, which limited the ability to detect a difference.

It should also be noted that all of the pilot participants were trained on glass cockpit systems, as opposed to analogue. This may have had an effect on their general comfort level with this type of display.

The second hypothesis statement held to be true because a significant difference between pilots and non-pilots was not found. This was expected because the purpose of the experiment was to make a recommendation for a temporal guidance system that was easy enough to use so that anyone could use it. Presumably this would make it more accessible to pilots and make the transition to a temporal guidance system easier. However, this means that the experiment was attempting to accept the null hypothesis to be true. This begs the question of how one can be certain that the lack of a difference between pilots and non-pilots was because of the effectiveness and simplicity of the display versus alternate explanations accounting for the lack of an effect. One way to be approach this would be to design a much more difficult experiment and continue to check for pilot/non-pilot differences.

The third hypothesis was held to be true because it was based on there not being a significant interaction between the independent variables. However, this conclusion must be taken carefully as it attempts to accept the null hypothesis in the same manner as the previous hypothesis.

There were slight differences between pilots and non-pilots in terms of display preference. See Table 3 for the percentages in terms of preference between groups. Fifty percent of pilots preferred the graphic display. However, preference of non-pilots was largely split between mixed and graphic displays. Based on feedback from pilots, they were generally more comfortable using the time box. Non-pilots seemed to be more reticent in the acceptance of the time box.

Anecdotally, participants that preferred the graphic display generally felt it was easier to use based on debriefing commentary. But more importantly, they liked it because everything they needed know was located in one place. Those that preferred the mixed display often stated that they like the security of more information. Many participants also crosschecked the temporal guidance information to make sure they were interpreting the information properly. All participants were also unfamiliar with the concept of Required Time of Arrival (RTA). However, after being introduced to RTA and instructed in its use and purpose, all participants were able to easily grasp the idea. Many pilots also commented that they thought it would be a very valuable tool.

Participants that preferred the text display generally thought it was less confusing and more simple to use. However, only about 18% of non-pilots preferred text only as opposed to 33% of pilots. This may suggest that pilots were slightly more comfortable interpreting hard data, whereas non-pilots appreciated and took advantage of the time box when available. Participants that preferred the mixed display felt they had more information available, leading to better situation awareness, even though their scores didn't reflect that.

The question should also be asked if there is the potential for overreliance on this type of display. With all displays there is the possibility of fixation, where a pilot becomes so focused on one piece of information and ultimately loses situation awareness. That is not necessarily the case here because the RTA symbology is concerned with showing longitudinal performance. Pilots are trained to have an

efficient scan across multiple displays and longitudinal performance alone is not enough to effectively navigate an aircraft.

Limitations

A major limitation in this experiment was that it wasn't a traditional situation awareness evaluation. Situation awareness involves developing a mental model over time that is constantly growing to form a more complete picture of one's environment (Endsley, 1989). The nature of this experiment didn't allow that mental model to develop. To do a more accurate evaluation of situation awareness a next step would involve a real time simulation with interruptive questions about temporal performance. This experiment attempted to compensate for that by having hazard information present; forcing the participants to pay attention to items other than guidance information.

Another possible limitation was the questions asked of the participants. One method to detect greater differences between pilots and non-pilots could be the degree of question difficulty. This could have been accomplished by having a greater variety of questions of greater complexity. During pilot testing a greater number of more specific questions were used. The participants were required to answer questions concerning navigation information, such as time-to-waypoint and waypoint call sign. It was decided that this level of difficulty was more akin to a memory task. Therefore, the questions were made to be of a more general nature. The number of questions asked was also reduced in order to have a larger sample

size per each question. A possible solution to this may be to have a longer experiment and simply ask more questions in various and with different wording.

Conclusion

The purpose of this paper was to research potential methods for displaying temporal guidance information to pilots. The research was important because trajectory-based operations will use arrival constraints at various waypoints in a flight plan in an effort to streamline the flow of air traffic. The method used to convey temporal guidance information will affect performance and acceptance by pilots. This study evaluated three methods of temporal guidance: Temporal information shown only as text; temporal information shown only as a graphic symbol; and, a combination of the two display methods. In terms of perception of information, both pilots and non-pilots using the graphic display received slightly higher mean scores. A clear majority of pilots also preferred the graphic only display. Some participants also liked the mixed display type because it gave them the option to choose which symbols they wanted to look at. They also liked being able to cross check information and verify the accurate perception of temporal information. All display types appeared to be effective in terms of communication of temporal information while maintains awareness of potential hazards. While there was no statistical difference in any of the display types, on average, the graphic display showed slightly better situation awareness scores.

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Appendix A

Answer Sheet

Participant Number:_____

Student ID:_____

Date:_____

Condition 1	Condition 2	Condition 3
1	1	1
2	2	2
3	3	3
4	4	4
5	5	5
6	6	6
7	7	7
8	8	8
9	9	9
10	10	10
11	11	11
12	12	12
13	13	13
14	14	14
15	15	15
16	16	16
17	17	17
18	18	18
19	19	19
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28	28	28
29	29	29
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31	31	31
32	32	32
33	33	33

34	34	34
35	35	35
36	36	36
37	37	37
38	38	38
39	39	39
40	40	40
41	41	41
42	42	42
43	43	43
44	44	44
45	45	45
46	46	46
47	47	47
48	48	48
49	49	49
50	50	50

Appendix B

Subjective Questionnaire (Please Print)

1. Which display type did you prefer?

2. Why?

3. Which did you feel led to a more complete understanding of your environment?

4. Why?

5. Do you have any comments or suggestions for how RTA error could be more easily understood?

Appendix C

AN EVALUATION OF RTA SYMBOLS TO MAXIMIZE PILOT SITUATION AWARENESS

Conducted by Erik Schmidt
Advisor: Dr. Sean Doherty
Embry-Riddle Aeronautical University
Department of Human Factors & Systems
600 S. Clyde Morris Blvd, Daytona Beach, FL 32114

      The experiment you are about to participate in is concerned with symbology for communicating temporal guidance information to pilots. The purpose is to investigate the advanced flight deck display concept of Required Time of Arrival (RTA). The experiment will consist of one, approximately one-hour session. You will be asked to interpret a variety of navigation displays. Your task will be to accurately determine your time error (if one exists) to your next waypoint. The display will be non-interactive, so you will simply have to interpret the display and answer the questions as accurately as possible.

      There are no known risks associated with this experiment. You will be competing against 11 other participants. The top performer in your group will be awarded $100, second place will receive $50, and third place will receive $25. You may terminate your participation at any time. If you terminate you session prior to completion you will forfeit the competition. Your assistance will help us determine the best method for displaying RTA error information to pilots.

      Thank you for your participation. If you have any questions, please don't hesitate to ask before or after the experiment or feel free to call me at 805-746-2454.

Statement of Consent

      I acknowledge that my participation in this experiment is entirely voluntary and that I am free to withdraw at any time. I have been informed as to the general scientific purpose of the experiment and that I will receive a remuneration fee of $100.00, $50.00, or $25.00 if I receive first, second, or third place respectively. If I withdraw from the experiment before its termination, I will forfeit any and all compensation.

Participant's name (please print):_____

Signature of participant:_____   Date:_____

Experimenter:_____   Date:_____

Appendix D

ID#:_____

Date:_____

Background Questionnaire

1. Do you have any pilot experience?

2. If so, how many rating do you have? How many total hours?

3. Do you have any medical problems?

4. Rate your skills with a computer from 1-10 (1 being low, 10 being high).

5. Rate your skills with video games from 1-10 (1 being low, 10 being high).

6. How often do you play video games (per day, week, or month)?

Debriefing

The experiment you just participated in is attempting to understand which type of display best facilitates superior situation awareness while communicating Required Time of Arrival (RTA) error. Making the presentation of RTA error intuitive is important because RTA is a tool that will likely be used in the very near future to provide temporal guidance to aircraft in an effort to increase airspace efficiency and capacity. The current study is attempting to determine which display maximizes temporal performance and situation awareness. Three different types were represented in the study:

1. Pure text symbol sets. RTA error was represented by a numerical value to the left of the waypoint of interest.
2. Pure graphical symbol sets. RTA error was represented by a graphic in the form of a time-line.
3. Mixed text and graphic symbol sets. RTA error was shown by both a graphical and numerical symbol set. A time-box was utilized to give a quick, intuitive method for assessing temporal performance. If the participant found there was an RTA to be concerned with, they would then refer to the numerical value to the left of the time box to determine their exact RTA error.

The current study changed the method for representing RTA error in an attempt to determine which method would increase temporal performance and maximize situation awareness. Your participation can help us determine which method is best for conveying temporal guidance information.

If you have any further questions, please contact Erik Schmidt at 805-746-2454 or via email at schmic88@my.erau.edu. Thank you once again for participating.

Appendix F

SAGAT Questionnaire

The following is a list of possible SA questions that will be asked after each slide:

1. Are you ahead of, behind, or on schedule?

2. Are you fast?

3. Are you slow?

4. Is there an aircraft hazard?

5. Is there a weather conflict?