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Assessing visual attention of pilots while using electronic moving maps for taxiing

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ASSESSING VISUAL ATTENTION OF PILOTS WHILE USING ELECTRONIC MOVING MAPS FOR TAXIING

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ABSTRACT

ASSESSING VISUAL ATTENTION OF PILOTS WHILE USING ELECTRONIC MOVING MAPS FOR TAXIING

by David Andrew Graeber

This study investigated the effect of visibility and training on allocation of visual attention while taxiing with an electronic moving map (EMM). An eye tracker was used to measure percent time of a trial dwelling on the EMM, number of dwells on the EMM, and average dwell duration both on the EMM and out the window (OTW). Performance data was also gathered to verify that the eye tracking apparatus was not altering normal taxi behavior. Survey and interview responses were gathered to assess allocation of visual attention and EMM usage strategies. The study also investigated route guidance preference, and the style "Yellow" was the unanimous favorite. The visual attention research revealed that attention was affected by both visibility and training. Research also showed that participants were using the EMM in a manner consistent with the display's design philosophy. These findings point to the conclusion that using EMM's for taxiing does not negatively impact heads-up, eyes-out taxiing and that training is crucial.

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TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

SECTION PAGE

TABLE OF CONTENTS

SECTION PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

Assessing Visual Attention of Pilots While Using Electronic Moving Maps for Taxiing

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Running head: ASSESSING VISUAL ATTENTION IN EMM USE

Footnote

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Abstract

This study investigated the effect of visibility and training on allocation of visual attention while taxiing with an electronic moving map (EMM). An eye tracker was used to measure percent time of a trial dwelling on the map, number of dwells on the EMM, and average dwell duration both on the EMM and out the window (OTW). In addition to the eye tracking data, performance data was also gathered to verify that the eye tracking apparatus was not altering normal taxi behavior. Survey and interview responses were gathered to assess allocation of visual attention and EMM usage strategies. The study also investigated route guidance preference, which was collected via survey answers. The style of route guidance that turned yellow beyond hold bars was the unanimous favorite. The research on allocation of visual attention revealed that attention was affected by both visibility and training. It also showed that the strategy the participants employed while using the EMM display was consistent with the philosophy guiding the display's design and intended use. The findings point to the conclusion that using EMM's for taxiing does not negatively impact heads-up, eyes-out taxiing. Instead, the benefits gained by implementing an EMM for taxiing as measured by performance and safety likely outweigh the inherent costs of adding a display to the cockpit.

Assessing Visual Attention of Pilots While Using Electronic Moving Maps for Taxiing

Why EMM's Were Developed

In the past decade, the National Airspace System (NAS) and major U.S. airports have become burdened with delays and over crowding. To resolve this, the U.S. aviation industry is investing $6 billion over a 20-year period to increase capacity. There is a serious differential, though, between industry's desired capacity and the capacity the NAS can handle. Recent Federal Aviation Administration (FAA) reports state that 23 of the largest U.S. airports experience more than 20,000 hours of delays each year; this figure is expected to increase to 40 major airports by the year 2000 (DOT/FAA, 1994). While these delays can be attributed to several factors, the two most prominent are weather and congestion. The FAA reported that between 1990 and 1993, an average of 312,000 flights per year were delayed more than 15 minutes, with 64% of these delays caused by poor weather, 28% by congestion, and 8% by other factors (DOT/FAA, 1994). In 1990, delays caused by weather and congestion were estimated to cost airline operations $3 billion. That figure jumps to $6 billion when passenger delays are factored in (DOT/FAA, 1994). With the airline industry's desire to increase capacity and the inability of the NAS to keep up, these figures are predicted to increase 50% in the next ten years based on current trends. To counteract these delays and economic losses, the root causes must be addressed, with particular emphasis on poor weather.

As noted above, 64% of the 312,000 15+ minute delays in 1990 were attributable to poor weather conditions. In a field study done by Andre (1995), a pilot remarked upon the effect of poor weather at SFO: "Recently at SFO, in dense fog, you couldn't tell where you were, you could only see the gate numbers lit up. It took almost one hour from gate to runway." While we cannot control weather, we can utilize technology to lessen the devastating effects of poor weather conditions.

Today's modern glass cockpit aircraft technologies allow an aircraft to land and depart in low visibility, but a lack of ground taxi technology creates a bottleneck in the flow of airport operations. Ground taxi is an essential element affecting the flow rates at airports, and poor weather poses many challenges to accomplishing this task. This bottleneck in ground taxiing conditions exists for two specific reasons. First, due to the technologically devoid state of ground taxi, pilots must rely on out the window (OTW) information. Typically, airports cease operations when visibility drops below a minimum runway visual range (RVR), potentially creating a ripple effect that delays schedules nationwide, especially if that airport is a hub. Second, if visibility is degraded from high visibility, but to a level still above the minimum, pilots taxi more slowly than in high visibility. A pilot confirmed this in Andre's (1995) field study when he remarked: "Under low-visibility conditions I taxi at 1/2 to 1/3 the speed of high-visibility conditions." Pilots also tend to make more navigation errors under such conditions. These navigation errors are likely to result in increased communication with air traffic control (ATC) and interference with other airplanes' cleared taxi routes, potentially disrupting the traffic pattern of the entire airport.

To address these issues, NASA's Terminal Area Productivity (TAP) program was developed, and specifically a taxiway navigation and situation awareness (T-NASA) system, in an effort to safely increase airport throughput in low-visibility conditions to that of a clear day. Currently, pilots taxi to and from the terminal using paper maps

(Jeppesen charts), OTW visual cues, and directions from ATC. The paper maps used in the cockpit are similar to those used by motorists for navigating. They show the layout of the airport in a north-up fashion and display all pertinent information (i.e., which radio frequencies to tune into, runway lengths, elevation changes, etc). For visual cues, pilots rely on taxiway centerlines, taxiway markers, hold bars painted on the taxiway's surface, landmarks (i.e., terminals, towers, etc.), and other aircraft. Other aircraft provide visual cues because ATC frequently gives clearances that direct a pilot to follow an aircraft type, or specific aircraft. This is the final component of current navigation methods, ATC clearances/directions. ATC acts as a shepherd and resource for taxiing aircraft. After receiving the initial clearance, pilots contact ATC to reconfirm their route, ask what other aircraft in the area are doing, and to help guide them back on course when lost. As one can see, this is a low-technology approach that could be improved using today's technology. In an attempt to introduce technology to this task, the T-NASA system, which consists of a HUD (Heads-Up Display), 3-D GCAW (3-D Ground Collision Avoidance Warning), and EMM (Electronic Moving Map), was created (Foyle, 1996). The component of interest here is the EMM.

EMM Benefits

Previous simulation studies pitting EMM's vs. paper maps have shown that the EMM alone, partialed out from the T-NASA system, produces significant improvements in performance over paper maps. In a part-task simulator study of the T-NASA components, McCann et al. (1996), showed that pilots made fewer navigation errors and could taxi at higher speeds when an EMM was present, in comparison to a paper-map-only condition. For example, analysis of the data showed a 1.5 kt increase in taxi speed with EMM in 700' runway visual range (RVR) in comparison to the paper map only condition in 700' RVR. They also noted that the EMM's benefits were even more pronounced in low-visibility conditions. In a simulation looking specifically at the differences between electronic and paper maps in navigating the airport surface, Batson et al. (1994) found more evidence supporting the use of EMM's. Batson et al. found that the average taxi speed increased as much as 24% under both good and poor visibility. This was due in part to the elimination of time used for orientation with the paper map. They also found that pilots made only one third as many errors and had better awareness during taxi when using an EMM. Analysis showed that pilots performed better with an electronic map than with a paper map under almost all combinations of visibility and route conditions, as measured by taxi speed, centerline tracking, and errors committed.

In a study looking at the T-NASA components, McCann et al. (1997) found that the EMM yielded a 0.76 kt increase in forward taxi speed in comparison to the baseline paper map only condition. He also found that, over seven departures, pilots averaged 2.3 navigational errors in the baseline and only 1 error in the EMM-alone condition. Irwin and Walter (1996) examined crew navigation strategies when errors were committed in Battiste's 1996 EMM study. They found that in nine of 19 cases where errors were committed using the EMM, crews were able to correct their errors without contacting ATC. They also found that the mean correction time was 93 seconds for the paper map condition and 31 seconds for the EMM condition.

From these studies and others it is apparent that EMM's have a positive effect on ground taxi performance in that pilots make fewer navigation errors and taxi at a greater speed in comparison to using a paper map. (Batson, Harris, & Hunt, 1994; Battiste et. al., 1996; McCann et. al., 1996; Tu & Andre, 1996; Zimmerman, 1994). From reviewing the past research, it is clear that EMM's provide economic benefits, increased safety, and reduce stress on visual, cognitive, and attentional resources. The gains provided by the EMM are not without hindrances though. One area of concern is the amount of heads-down-eyes-in time a cockpit display produces. To understand why heads-down-eyes-in time is a concern, we need to examine the task of taxiing and visual attention.

The Task: Taxi

Before delving into how and why the EMM is integral to the success of the T-NASA system, we must first examine the task of taxiing itself and the pilot's requirements to perform this task. Lasswell and Wickens (1995) mention five components that comprise the task of taxiing: (1) Lateral loop closure (i.e., minimize lateral deviations from taxiway centerline); (2) directional loop closure (negotiate turns, etc.); (3) longitudinal loop closure (i.e., maintain optimal speed, brake for HOLD markings and other traffic, etc.); (4) information gathering inside and outside the aircraft (i.e., monitor cockpit instruments and displays, read taxiway signs and markings); and, (5) hazard detection (i.e., monitor for ground traffic obstacles). These tasks fall into two categories, local guidance (lateral loop closure, directional loop closure, longitudinal loop closure, and information gathering inside the aircraft) and global awareness (information gathering outside the aircraft and hazard detection). For the human operator to be able to perform the taxiing task while maintaining local guidance and global awareness, certain perceptual and cognitive resources are required.

Resources Required for Taxi: Foveal vision

In many ways, driving an automobile and taxiing an aircraft are similar tasks. When we drive an automobile we glean most of our information from the visual system; the same holds true for taxiing an aircraft. While driving, it has been estimated that visual input accounts for about 90% of the perceptual information utilized (Rockwell, 1972). When taxiing, pilots acquire necessary visual information via peripheral and foveal vision to navigate the airport surface.

Foveal vision, because of its high-resolution capabilities, allows detailed information to be gathered. In order to attain high resolution, the lens of the eye must make accommodative changes when the eyes fluctuate between the near and far domains. Another feature of foveal vision is that it is limited to a two-degree field-of-view (Rockwell, 1972). This effectively inhibits us from simultaneously extracting detailed information from sources that are greater than two degrees apart. In other words, pilots are unable to monitor a head-down-eyes-in instrument while scanning the OTW scene for global cues.

Resources Required for Taxi: Cognitive attention.

In addition to foveal vision, automobile drivers and pilots must also utilize cognitive attention. Dingus and Hulse (1993) define the ability to process perceptual information (i.e., foveal input), as cognitive attention. As we all know and have experienced, it is possible to focus our foveal vision upon something and not actually process the input, for example, when we daydream. Therefore, it is critical that cognitive attention be tapped, but not over-loaded, in conjunction with the visual input received from the fovea. During the task of taxiing there are several parameters that may differ among pilots (familiarity with the airport), airports (ground traffic activity and geographical features of the taxiway), and meteorological conditions. Along with the parameters mentioned above, other tasks (e.g., communication with ATC, completion of checklists, etc.) require cognitive attention, which, when combined with the aforementioned parameters, pose diverse demands on pilots. It is essential that the task of taxiing does not surpass the pilot's attentional limits. One of T-NASA's objectives is to keep the attention required of the pilot below this point of performance decline.

Information Sources for Taxi: OTW & eyes-in

To complete the explanation of the taxiing task and what is required of the pilot to perform it, we must look at the sources of informational input for the task and pilot. For the two types of information that pilots must obtain to perform the taxiing task (i.e., local guidance and global awareness), we can identify the sources of input needed to glean that information. With regard to local guidance (i.e., maneuvering the aircraft along a cleared taxi route), there are five tasks that require information to be gathered from the OTW scene. These tasks include lateral loop closure, directional loop closure, information gathering, longitudinal loop closure, and hazard detection. It should be noted here that longitudinal loop closure and hazard detection also require monitoring the cockpit instruments and displays, along with scanning the OTW scene. Conversely, global awareness (i.e., maintaining awareness of position relative to airport features, destination, etc.), exclusively utilizes cockpit instrumentation and displays in low-visibility. Thus, most of the information needed to complete the taxiing task is acquired from the OTW scene. However, it is important to integrate information acquired from both domains that is related or redundant. Therefore, it is critical that the information presented on the EMM supports optimal allocation of visual, attentional, and cognitive resources.

Visual Attention

As with all displays introduced into the cockpit of an aircraft, there are concerns that the EMM may draw the pilot's eyes into the cockpit during taxi. With the exception of scrutinizing the paper map and contacting ground control, taxiing is an eyes-out task. Pilots navigate the airport and terminal areas using signage. They manually control the aircraft using visual cues from the environment, monitor for potential incursions, and maintain a safe distance from other aircraft, ground vehicles, and obstacles by keeping their heads up and eyes out the cockpit windshield. Keeping "eyes out" supports safe control of the aircraft, efficient information gathering, and detection of hazards.

Andre (1995) noted that coupled with the excitement surrounding the EMM, there was concern about adding an eyes-in display to assist an eyes-out task. Several pilots had comments regarding this concern, including the following: "I don't want a display that keeps me heads-down while taxiing. Even at night and in poor weather I see things out the window (lights on other aircraft, runway markers)"; "I like the idea of a moving map display for taxi operations, but it should be a secondary display, not a primary display, since it requires me to be heads down." Not only are the pilots concerned with this issue, but past research has shown that EMM usage does increase eyes-in time and the potential to miss events in the OTW scene (Battiste, 1996). While there is an inherent cost in each cockpit display in that the eyes need to be brought in to process the information, the key question is whether or not the cost is operationally significant.

In driving simulation research, Wierwille, Hulse, Fischer, and Dingus (1991) found that drivers adapt reliably and appropriately to both anticipated and unanticipated increases in driving task demand while using an in-vehicle navigation system. Conversely, there is the cost of the time it takes the eyes to refocus when switching between the display and OTW scene. While each of these findings support conflicting sides of the question, there is still potential for failure to detect events in one domain while fixating in the other.

Work by Battiste et al. (1996) looked at average head-up time, average duration of head-down response, and frequency of head-down responses of pilots taxiing in a Boeing 747 simulator. They defined average head-up time as the total time the crewmember spent looking out the windshield with his/her head up, measured as a percentage of overall taxi time. They found that Captains' heads-up time was significantly reduced with the introduction of an EMM. Captains averaged 84% heads-up time with the paper map, and 65% head-up time with an EMM. Interestingly, crew feedback suggested that the disparity in head-up time between the paper-map and EMM conditions was due to the amount of time needed to acquire and process information from a paper map. In other words, the taxiing crew member spent more time eyes-out in the paper map condition because it was harder to extract the necessary information; therefore the task of extracting the information was passed onto the other crew member and sampling frequency was at minimal levels.

The ease with which information could be extracted was analyzed using duration of head-down time. Head-down time was defined as the average amount of time spent eyes-in before looking back out the windshield. When Captains were taxiing, their head-down interval was reduced significantly with an EMM in comparison to the paper map. In the paper map only condition, average head-down duration was two seconds; with an EMM, head-down time was only 1.25 seconds. The difference represents a 32% reduction in map assessment time. The same trend was found for First Officers.

Similarly, as the increased percent time of head-down resulting from EMM use, the frequency of head-down intervals also increased. Battiste et al. found that when Captains were taxiing with an EMM, their head-down frequency was increased 170% over Captains in the paper map group. The mean head-down count for the paper map was 28, in contrast to 74 for their EMM. A similar result was found for First Officers, paper map 34 and 49 for their EMM. The increased frequency and shorter head down interval suggests that their EMM supported navigation and situational awareness more efficiently than a Jeppesen chart.

In summary, Battiste et al. found that the EMM version they used in comparison to a paper chart led to an increase in percent time heads-down, most likely due to the ease of reading an EMM in comparison to a paper chart. They also found that the average head-down time decreased with their EMM, reconfirming that EMM's are easier to read than paper charts. Finally, Battiste et al. found that with an EMM, the frequency of head-down responses increased.

<u>EMM Design: Philosophy</u>

With the aforementioned findings in mind and an understanding of the taxi task, the T-NASA team developed an EMM with the philosophy of supporting eyes-out taxiing. The EMM in the T-NASA system is designed to be a secondary navigation display that aids situational awareness, navigation, orientation, and planning. It is not meant for controlling the aircraft, i.e., steering or tracking the centerline. Referring back to the local guidance vs. global awareness framework, the EMM was designed to support allocation of resources for global awareness, not local guidance. Since this display is designed for low-visibility conditions, instead of no-visibility, it was deemed unnecessary and not optimal to support the local guidance tasks that utilize the OTW scene. This was done in an effort to keep the pilot eyes-out while taxiing.

What's Missing?: Visual attention

It is the aim of this study to understand how the visual attention of pilots using EMM's is affected by visibility and instructions. Since EMM's use currently available display real estate in the cockpit, it is virtually assured that they will be introduced into the next generation of commercial aircraft. This likelihood increases the importance of researching visual attention issues now.

Battiste et al.'s (1996) study has provided insight into an EMM's effect upon frequency and duration of heads-down time in comparison to Jeppesen charts. However, with the possibility of outfitting aircraft with EMM's in the near future we need to focus on how visual attention is affected by visibility and training when using EMM's. These are important issues that need to be reviewed if EMM's are to become common place in tomorrow's cockpit. An eye-tracking methodology was used in the present study to assess allocation of visual attention.

Eye Tracking: Method for assessing visual attention

An increasingly common method for assessing visual attention and usability of products and displays is to track eye movements and fixations. From studying eye movements patterns, dwell duration, and mean number of dwells, usage trends can be determined. An eye tracking approach was agreed upon because it would allow us to compile accurate measurements of average dwell time, number of dwells, and percentage of a trial dwelling on the EMM, allowing for the understanding of how pilots are using the EMM to aid them while taxiing. What follows is a brief description of the eye tracking technology.

Eye Tracking: The technology

In brief, the eye-tracking system projects a beam of collimated, non-visible, infrared light at one of the participant's eyes and two reflections from the eye project back to a video camera. The first reflection is off of the retina, bounded by the pupil; similar to a cat's eye reflecting the light from a car's headlight. The second reflection is an intense pinpoint reflection from the surface of the cornea. From the video signal of the eye's reflections, the computer determines the center of each reflection. Based upon their relative positions the eye tracker calculates and updates the foveal point of gaze at a 60 Hz rate. Videotape of the environment and the pilot's superimposed point of gaze can be recorded, along with the point of gaze coordinates and pupil diameter. The aircraft state variables, pilot control inputs, environmental states, map states, time stamp, and other measures of interests can also be recorded at 60 Hz for correlation with gaze point.

Visual Attention: Mediated by visibility?

OTW visibility is an important manipulation for investigating visual attention and usage behavior with the map. It was expected that differences in strategy of use and role of the display in taxiing would arise for different OTW visibilities. Previous studies have looked at EMM's in daytime low-visibility (700' RVR or less). No studies, however, have investigated how use differs between levels of visibility and time of day. In this study, we will present the EMM to the user in three different combinations of visibility and time of day: daytime high visibility (Day VMC), daytime low visibility (Day 700' RVR), and nighttime moderate visibility (Night 1,400' RVR). As the visibility degrades or time of day progresses, we should see an increase of the percent of time dwelling on the EMM, an increase in dwell duration on the EMM and a decrease in dwell duration OTW, and increased number of dwells.

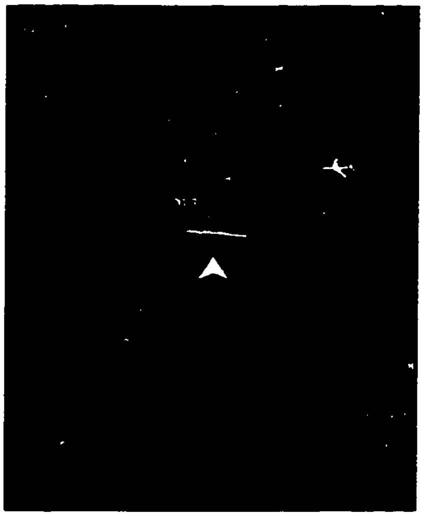
Visual Attention: Mediated by instructions?

One key component of the present study is the effect that instructions may have on visual attention. By giving one group of subjects detailed instructions on how and when the display should be used, it is assumed that their visual attention will differ from the group not receiving the usage instructions.

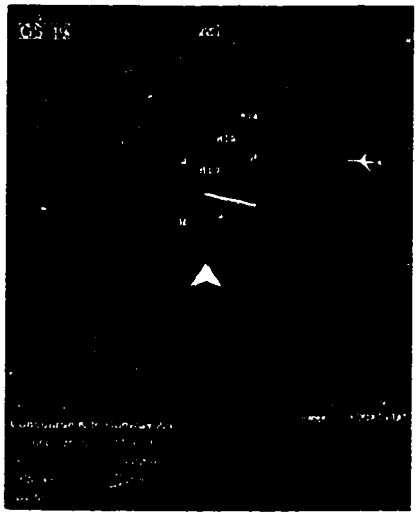
The usage instructions emphasized that this display is designed to be a secondary navigation aid, not a replacement for an eyes-out approach to taxiing. We also suggested optimal and non-optimal ways to use the display. The optimal behaviors include verifying heading, position, position relative to the cleared taxi route, cleared taxi route, ground speed, traffic, and hold bars. The non-optimal behaviors included using the display to control the aircraft through turns, taxiing eyes-in and not scanning the OTW environment, and using the ownship icon to track the taxiway centerline and the location of the aircraft's landing gear respectively. It is hypothesized that the group receiving the instructions will have a lower percentage of trial dwelling on the EMM, shorter dwell duration on the EMM and a longer dwell duration OTW, and a lower number of dwells. The instructions are described in detail in the method section.

Route Guidance: Preference

This study is not only aimed at investigating the allocation of pilot's visual attention, but also evaluating the display's features, in particular, the route guidance features. In this study, there were three versions of route guidance presentation beyond a hold bar. A hold bar is a pictorial representation on the EMM of an ATC command to stop the aircraft. When a hold bar was placed on the map by either ATC, or due to a potential incursion, the magenta route guidance stripe beyond the hold bar did one of three things: turned yellow, disappeared, or remained magenta (see Figure 1 for a picture of each route guidance style). The route guidance stripe before the hold bar remained magenta.



Route guidance style "Yellow".



Route guidance style "Disappear".

Route guidance style "Magenta".

Figure 1. Pictures of the Three Route Guidance Styles.

It has been noted in previous studies through pilot feedback that they use the magenta route guidance stripe for route planning before beginning taxi and while stopped at hold bars en-route. It has also been noted that displaying the magenta route guidance stripe beyond the hold bar is somewhat misleading. The three manipulations of the route guidance stripe being tested are the result of pilot feedback stating that leaving the route guidance stripe magenta beyond the hold bar is misleading because it implies that the aircraft is clear to continue taxiing. The goal here was to assess which design is preferred for presenting the route guidance beyond a hold bar. Based on the pilot feedback described above we expect "Yellow" to be the favored style.

Heading Bars: Preference

On the map, four distinctly colored bars frame the EMM and represent the four cardinal headings, North (gray), South (green), East (blue), and West (brown). Each bar represents a 90-degree range of heading, for example, the gray North bar ranges from 315 degrees to 45 degrees. The point where two bars meet represents the average of the two headings, i.e. where the gray North bar and brown West bar meet represents a Northwest heading of 315 degrees (see Figure 2 for a picture of the EMM with heading bars).

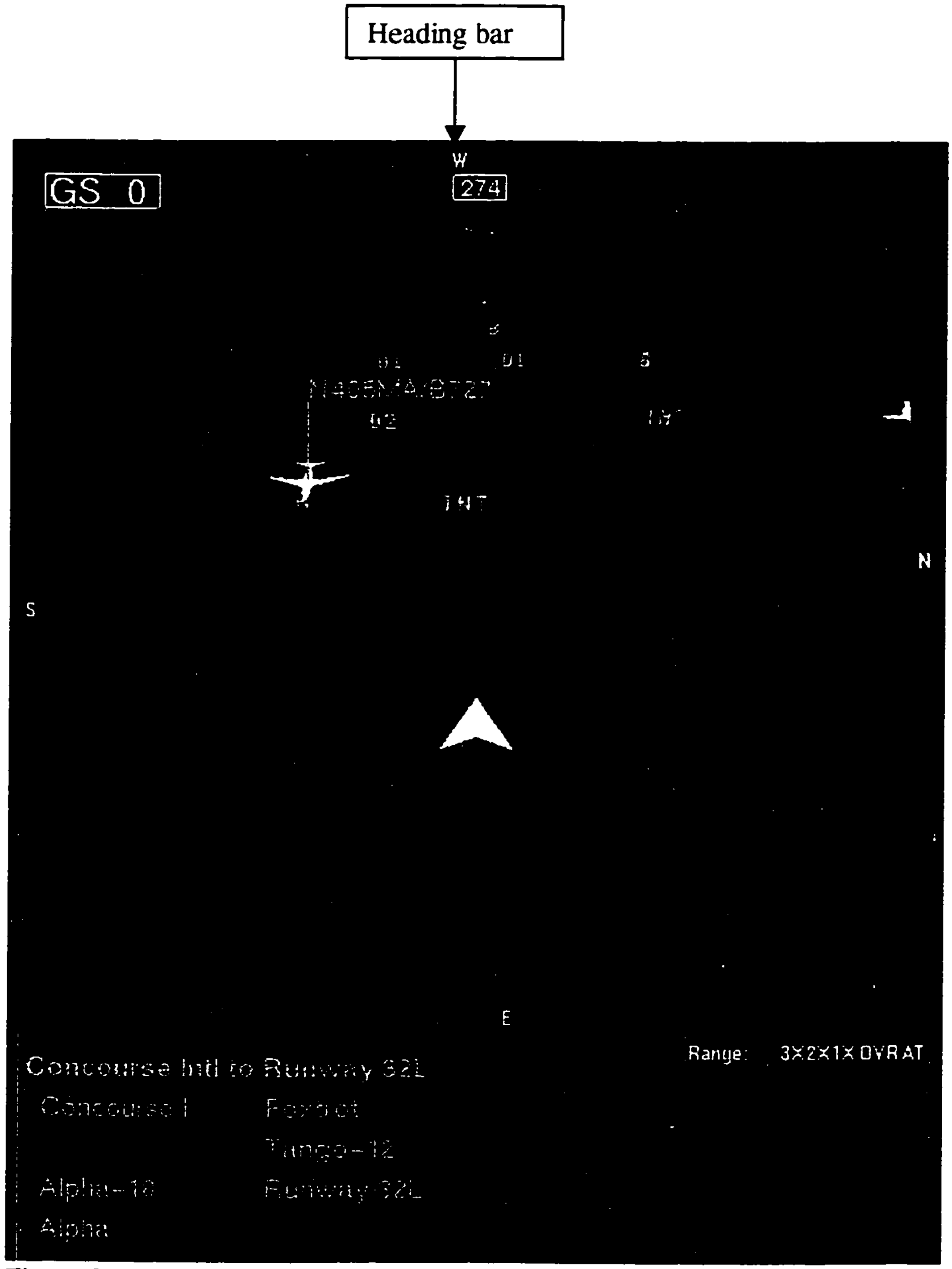


Figure 2. Picture of the EMM with Heading Bars.

The purpose of these color-coded heading bars is three fold. The first purpose of the heading bars is to assist with compliance of clearances given by ATC that use cardinal headings. Through field observations (Andre, 1995) it has been noted that taxi routes and mid-route changes are often given using the cardinal directions of North, South, East, and West. By providing heading bars that are distinctly labeled and color coded for each heading the pilots only have to glance at the map to see which direction the aircraft needs to be turned to be oriented in the correct heading. This brings up the second purpose of the heading bars; they eliminate the need for mental calculation when switching between cardinal headings and numerical headings. By providing both numerical heading via a digital compass and the heading bars the need to convert numerical headings into cardinal headings when communicating with ATC or the crew is eliminated. In addition to eliminating the need for mental calculations, the heading bars also facilitate communications with ATC. The third purpose for having the heading bars is that they are easier to read and can be processed quicker than a numerical heading. This is due to the fact that the heading bars are redundantly coded with color and labels in addition to their size and omnipresent nature.

Heading bars were included in the present study to evaluate their use: in orienting the aircraft when ATC does not use cardinal headings and when pilots are given mid-route route changes in cardinal headings; and, when communicating with ATC about headings. To do this we included two mid-route route changes in a block of four additional trials at the conclusion of the experiment.

Visual Attention: Allocation during incursions

In a previous study (McCann et al., 1997), the effectiveness of the EMM display to aid detection of potential incursions was investigated. The results from these studies showed that the presence of the map display improved detection of, and decreased reaction time to, potential incursions in comparison to no electronic aids. With these findings in mind we decided to investigate how visual attention is allocated during incursion incidents. As a result, two incursion trials in the block of four additional trials were included. The goal was to find through interview data and incursion detection performance data a particular strategy for using the EMM in incursion situations, and investigate that role in detection of incursions and subsequent direction of visual attention during incursion situations. We hypothesize that the EMM will help identify potential incursions and focus the visual attention of the pilots out the window to the general location of the incursion, resulting in a high rate of incursion detection.

The Present Study

In this study, three independent variables, Instructions, Visibility, and Route Guidance were manipulated in a mixed factorial design. Performance measures used were percent time on route, average moving speed, average planning time, number of navigation errors, EMM range level use, and incursion detection. The aforementioned data were collected to make sure the eye tracking apparatus had no effect on the pilots' taxiing. Eye-tracking data on percent time of trial dwelling on the EMM, number of dwells on the EMM, and average dwell duration on the EMM and OTW were collected to assess visual attention. Finally, survey and interview data were collected to assess EMM usage strategies and design preferences.

From this information, it is hoped to be able to distinguish the role the map plays in taxiing from the pilots' strategy in using it, and to clarify how these strategies and roles are affected by visibility and training. Finally, questionnaires and interviews were conducted to acquire feedback to guide future revisions of the display.

Method

Participants

A total of 12 participants were tested, all of whom were commercial line pilots, six captains and six first officers, with taxiing experience. All twelve of the participants had flown as a flight deck crewmember into or out of Chicago's O'Hare Airport. Of the 12 participants, three rated themselves as very familiar, seven were moderately familiar, and two were slightly familiar with the airport's layout. Among the 12 participants, two were very experienced in taxiing at O'Hare during VMC, four were moderately experienced taxiing at O'Hare in VMC, and six were either not experienced or slightly experienced at taxiing at O'Hare in VMC. The distribution was the same for taxiing at O'Hare at night, but for low visibility, 10 of the 12 participants were either not experienced or slightly experienced.

In regards to previous experience with EMM's, only 2 of the 12 participants had previously used one in an automobile. Simulator experience was also assessed. The mean number of hours spent taxiing in a simulator was 6.9 hrs with a standard deviation of 5.3 hrs. The mean number of hours for overall simulation time was 191.3 hrs with a standard deviation of 87.3 hrs. To facilitate the use of the eye tracker only participants with uncorrected vision, or soft contact lenses, and without color vision deficiencies were used.

Design

Pilot Instructions were manipulated between subjects; Visibility and Route Guidance were manipulated within subjects creating a mixed factorial design. The between-participants variable, Pilot Instructions, had two conditions: pilots given instructions regarding map usage (Instructions) vs. pilots not given usage instructions (No Instructions). The within-participants variables, Visibility and Route Guidance, each had three conditions. Visibility consisted of Daytime VMC (DV), Daytime 700' RVR (D7), and Nighttime 1,400' RVR (N14). Route Guidance was made up of Magenta (M), Disappear (D), and Yellow (Y). These variables comprised the first block of nine trials and the bulk of the experiment. In addition to these nine trials we also ran four additional trials for each participant to investigate the use of the heading bars during mid-route route changes and visual attention during incursions. These four extra trials were tested in Daytime 700' RVR and used the Yellow style of route guidance. A total of 12 participants were tested.

Apparatus

The hardware used for the experiment consisted of several components. The simulated environment was created using a Silicon Graphics Indigo 2 Extreme and projected onto a 6' high by 8' wide screen 8' from the participant's eye point using a Stuart Films Screen rear-projection unit. Two side windows were also present and were displayed on two 19" Silicon Graphics monitors 3' from the participant's eye point. An Indigo 2 Maximum Impact was used to create the EMM. In the part task simulator, the EMM appeared as an 8" x 6" display on a 17" Sony Trinitron monitor 3.5' from the participant's eye point. The participant was seated in an adjustable seat from a Chrysler Laser that was mounted on a motorized sliding track. In order to control the simulated aircraft, a Boeing 737, the participant was provided a throttle, tiller with left and right incursion response buttons, and rudder pedals with toe brakes. To manipulate the EMM, input devices were mounted to the right of the throttle. Controls included an adjustable knob to change map range levels and a toggle switch to activate/deactivate the inset.

The experimenter's station consisted of four 19" Silicon Graphics monitors, one displaying the simulated OTW scene, one displaying a map for ATC, one showing the participant's EMM, and the other was a simulation control interface. To track eye movements an ASL (Applied Science Laboratories) Series 5000 Integrated Eye/Head tracking system was used. The computer, monitor and control box for the integrated eye/head tracking unit was placed on a cart in the experimental room, while the participant wore the optics mounted on an adjustable hockey helmet. Verbal "hold short" commands were driven by the computer running the OTW scene and were produced by a Roland S-760 sampler. Pilots were given a headset, with "hot mic", to communicate with the experimenter/ATC.

Simulated Environment

The simulated OTW scene projected on the 6' x 8' screen and the two 19" monitors was a recreation of Chicago O'Hare airport based on 1991 CAD representations. The OTW scene perspective was modeled using pilot eye point, acceleration, braking, and turning characteristics of a Boeing 737. The OTW scene, updated at a rate of 30Hz, included all operational runways, taxiways, taxiway and runway signs, gate markers, terminals, buildings, control tower, taxiway and runway lights, and other landmarks. The

EMM displayed on the 17" Sony Trinitron was updated at a rate of 15Hz and was based upon the same representation used to build the OTW scene.

Procedure

Participants were met in a room separate from the part-task simulator. At this time, they were given a low-risk consent form (see Appendix B) to sign and a demographics form (see Appendix C) to fill out. All participants were then given a set of general instructions explaining their tasks (Appendix D) and a set of instructions explaining the map features (Appendix E). The participants assigned to the group receiving EMM usage instructions were given them to read at this time (Appendix F). The usage instructions explained that the EMM was to be used as a secondary navigation aid, not a primary display. In other words, they were told that it was designed to supplement situational awareness, global awareness, and hazard detection. It was emphasized that the map was not an aid for centerline tracking, should not be used for steering the aircraft, and that eyes should be kept OTW while incorporating the EMM into a scan pattern. The participants were also given examples of what we deemed optimal and non-optimal usage of the display.

Next, participants were seated in the part-task simulator and the simulated environment and EMM were displayed. After answering questions regarding the map's features and controls, the participants were instructed as to how the throttle, tiller, rudder pedals, toe breaks, and incursion response buttons worked. After answering any questions regarding the aircraft control devices, the participant was given a chance to practice taxiing around O'Hare airport. The practice trial included traffic that was represented on the map and in the OTW scene. In this practice trial, one of the traffic aircraft was designated an incursion. After explaining how the traffic on the map was displayed and that the update rate of the traffic and ownship (OS) icon on the EMM was 15Hz, the pilot was free to taxi along a specified route. When the pilot neared the pre-determined incursion point, he/she was instructed to slow the aircraft to five knots while the experimenter explained how the EMM would represent the incurring aircraft and hold bars. The experimenter also explained how to respond to the incurring aircraft using the response buttons mounted on the left and right side of the tiller. If the incursion was approaching from the left of the aircraft's nose at the time the traffic icon began flashing red on the EMM they were to use the response button on the left side of the tiller, and vice versa. Pilots were also instructed that if they missed detecting the incurring aircraft, the hold bar on the map would be accompanied by an auditory "hold short" alert. Participants were then instructed to taxi at five knots up to the incursion event for a demonstration of the auditory alerts and the EMM alert. After the incursion incident, they were free to throttle up and finish the practice trial. At this point, participants were given a five-minute break before calibrating the integrated eye/head-tracking unit.

To calibrate the integrated eye/head-tracking unit, a set of nine (1-9) numbers were brought up on the screen where the EMM was previously projected. These numbers were in three rows of three, i.e., the top row was numbers 1-3, and were spaced 2" apart horizontally and 2.66" vertically. The participant was seated in a chair 2' from the screen displaying the calibration points and donned the helmet mounted with the optics. The helmet and chinstrap were adjusted to fit snugly on the participant's head to keep slippage to a minimum. The reflective glass plate and pupil/corneal reflection laser were then adjusted until a clear image of both the cornea and pupil appeared on the ASL eye tracking monitor. The participant was then asked to hold his/her head still. Next, participants were instructed to fixate, with minimal blinking, on each calibration point as the experimenter called out its number. When good pupil and corneal reflections were obtained, and the participant was not blinking, the experimenter entered the calibration point by pressing the space bar and the participant was instructed to fixate on the next calibration point. After calibrating for all nine points, the participants were instructed to look at the nine numbers in sequential order and to look at the side windows and rear projection screen to verify that the integrated eye/head tracking equipment was functional and veridical. The entire process, from donning the helmet to ending the functional verification, was approximately five minutes. At this point, the calibration plane was taken off of the monitor where the EMM was displayed and the part-task simulation was started.

Participants proceeded through nine trials, grouped by visibility. At the beginning of each trial, ATC (the experimenter), read the clearance text to the pilot and the pilot confirmed by repeating the clearance. After responding, the pilot was cleared to taxi. Communications between ATC and the pilot during trials was limited to situations where the pilot was off route, busted "hold short" commands, asked for directions or present location from ATC, or asked ATC questions regarding other aircraft.

Each trial took approximately four to six minutes. After completing the last of the 9 trials the participants removed the helmet and were given the first survey. After completing the survey, the participants were given a ten-minute break.

Before beginning the final block of four additional trials the eye tracking headgear was donned and recalibrated. In these final four trials, the first and last were incursion trials and the middle two were route changes. These trials were all done in Daytime 700' RVR with the Yellow route guidance manipulation.

Incursion trials were trials in which one piece of traffic was designated as an incurring piece of traffic. An algorithm based on time to impact and distance was built into the incurring piece of traffic so that it would incur the ownship (OS). In other words, the OS and incurring piece of traffic were linked so that an incursion was imminent. Impact could only be avoided by correctly responding to the alerting logic on the EMM (traffic symbol turns red and begins to flash) or holding short when instructed to do so. The pilot was given a window of time, maximum of three seconds based on time to impact and distance, to press the correct incursion response button on the tiller. If an incorrect or null response was given, then an auditory "hold short" command was given and a yellow hold bar was placed over the route guidance. If a correct response was made a "cleared to cross" command was given and the yellow hold bar was placed in front of the incurring piece of traffic's icon on the EMM.

For trials in which a mid-route route change was given to the participant by ATC they were given the new clearance in stages to avoid writing down the new clearance. Each stage of the new clearance was given two taxiways in advance. They were also instructed that the graphical route guidance and clearance text would not change to conform to the new clearance. After completing the final four trials the subjects removed the helmet, were given the final survey, interviewed, debriefed, and thanked for their participation.

<u>Dependent Variables</u>

In regards to performance measures, the dependent variables of percent time on route, average moving speed, number of navigation errors, average planning time, map range level use, and incursion detection data were collected. These were collected to verify that the eye tracking apparatus did not affect taxi behavior. The eye tracking dependent variables were number of dwells on the EMM, average dwell time on the EMM and OTW, and percentage of taxi time dwelling on the EMM.

In addition to the above objective data, we also collected subjective data via surveys and interviews. There were two surveys, the first for the block of nine experimental trials and the second for the additional four trials examining route changes and incursions. The first survey (Appendix G) focused on the route guidance manipulation and questions regarding strategies for use and role of the EMM during taxi in the varying visibility conditions. The second survey (Appendix H) focused on map features, with emphasis on the heading bars, and questions regarding the design of an ATIS setting. Finally, the debriefing interview (Appendix I) queried map usage strategies in each visibility condition, the role the map played in taxiing, the strategy for using the EMM in resolving incursion incidents, and how the display would alter scan patterns in everyday operations.

Results

To analyze the data, mixed-design full-factorial Analysis of Variance (ANOVA) were conducted. For the eye tracking and performance data, a 3 (Visibility: Day VMC, Day 700' RVR, Night 1,400' RVR) x 2 (Instructions: Present, Absent) analysis was conducted, except for average fixation time, which required a 3 (Visibility: Day VMC, Day 700' RVR, Night 1,400' RVR) x 2 (Instructions: Yes, No) x 2 (Dwell location: EMM, OTW) analysis. Instructions was a between-participants variable, while Visibility and Dwell Location were within-participants variables. When relevant, Studentized Newman-Keuls post hoc tests were conducted. Alpha for all ANOVA's and post hoc tests was set at .05.

The analyses were done, and subsequent results section written, in a manner that supports the section that follows it. The analyses began by reviewing the performance data to prove that the eye tracking equipment did not alter taxi behavior. This was done by comparing the findings from this study to previous studies on EMM use. We hypothesized that the eye tracking equipment would not alter the participants' taxi behavior. The analyses then move to the eye tracking data to assess the effect of visibility and instructions on visual attention. We predicted that as visibility degrades and time of day progresses, we would see an increase of percent of trial dwelling on the EMM, an increase in dwell duration on the EMM and a decrease in dwell duration OTW, and increased number of EMM dwells. We also hypothesized that the instructions would result in differences between the groups for percentage of trial dwelling on the EMM, EMM dwell duration, and number of EMM dwells.

Finally, in order to determine EMM usage strategies, subjective survey data on route guidance preference, and heading bar use were analyzed. It was predicted that the Yellow route guidance style would be preferred. The subjective data was also examined in conjunction with the objective eye tracking data to verify survey responses. Finally, the interview questions were analyzed individually, in conjunction with each other, and in conjunction with the objective eye tracking data.

Performance Data: Percent time on route

There was a main effect of Visibility, $F(2,20) = 4.04$, $p < .05$. A post hoc test of the visibility main effect showed that percent time on route was significantly greater for Night 1,400’ RVR (99.9%) than for Day VMC (97.5%), but not significantly different from Day 700’ RVR (99.2%). Day 700’ RVR was not significantly different from Day VMC either (see Figure 3 for a graph of the means and standard errors). There was no main effect for Instructions, nor an interaction of Visibility by Instructions.

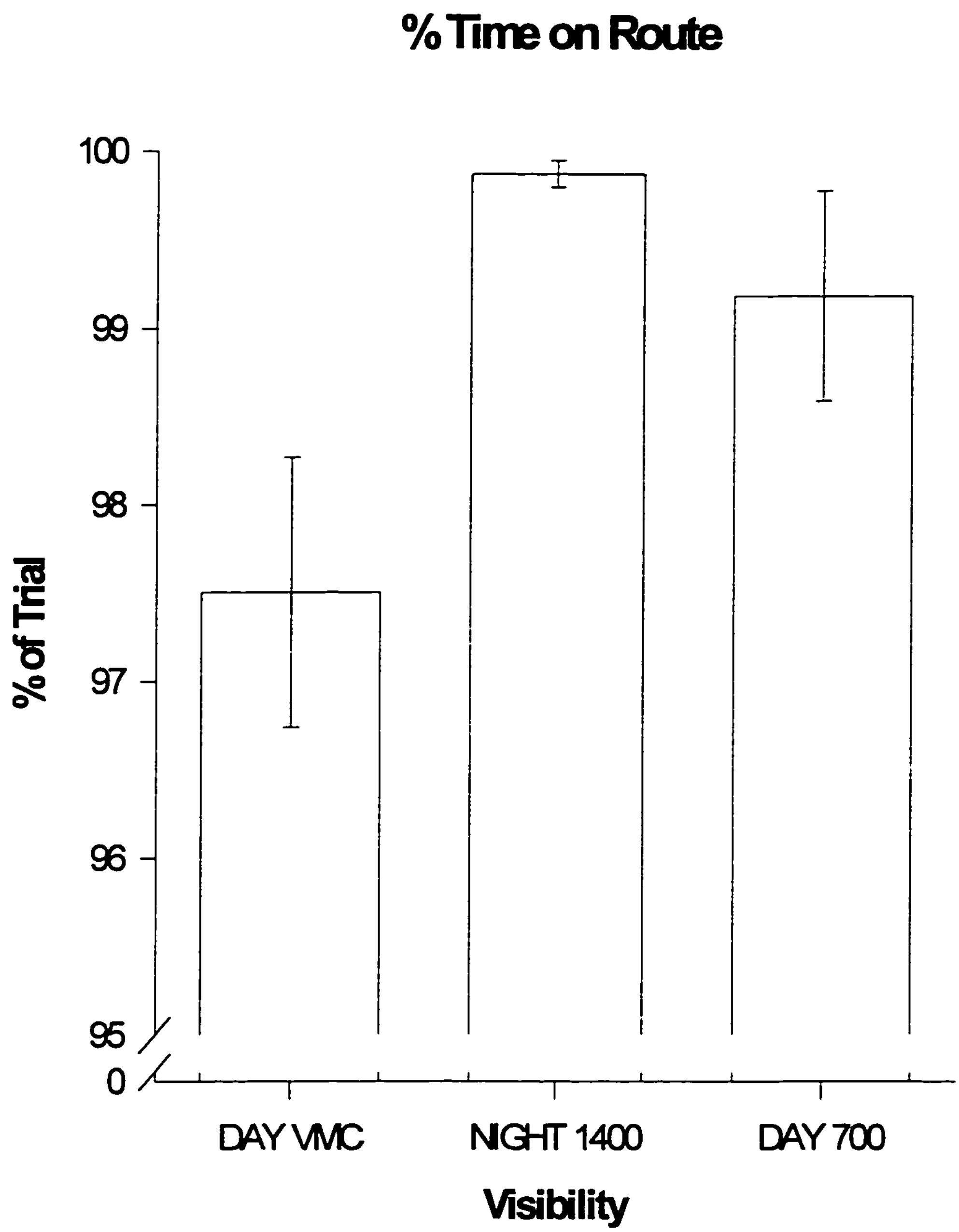


Figure 3. Means with Standard Error Bars for Percent Time on Route.

Performance Data: Mean moving speed

There was a main effect of Visibility, $F(2,20) = 9.29$, $p < .05$. Post hoc test of the visibility main effect showed that average moving speed was significantly slower for Night 1,400' RVR (12 kts) than for Day VMC (13.9 kts) and Day 700' RVR (15.4 kts). However, there was no significant difference between Day VMC and Day 700' RVR (see Figure 4 for a graph of the means and standard errors). There was no main effect for Instructions, nor an interaction of Visibility by Instructions.

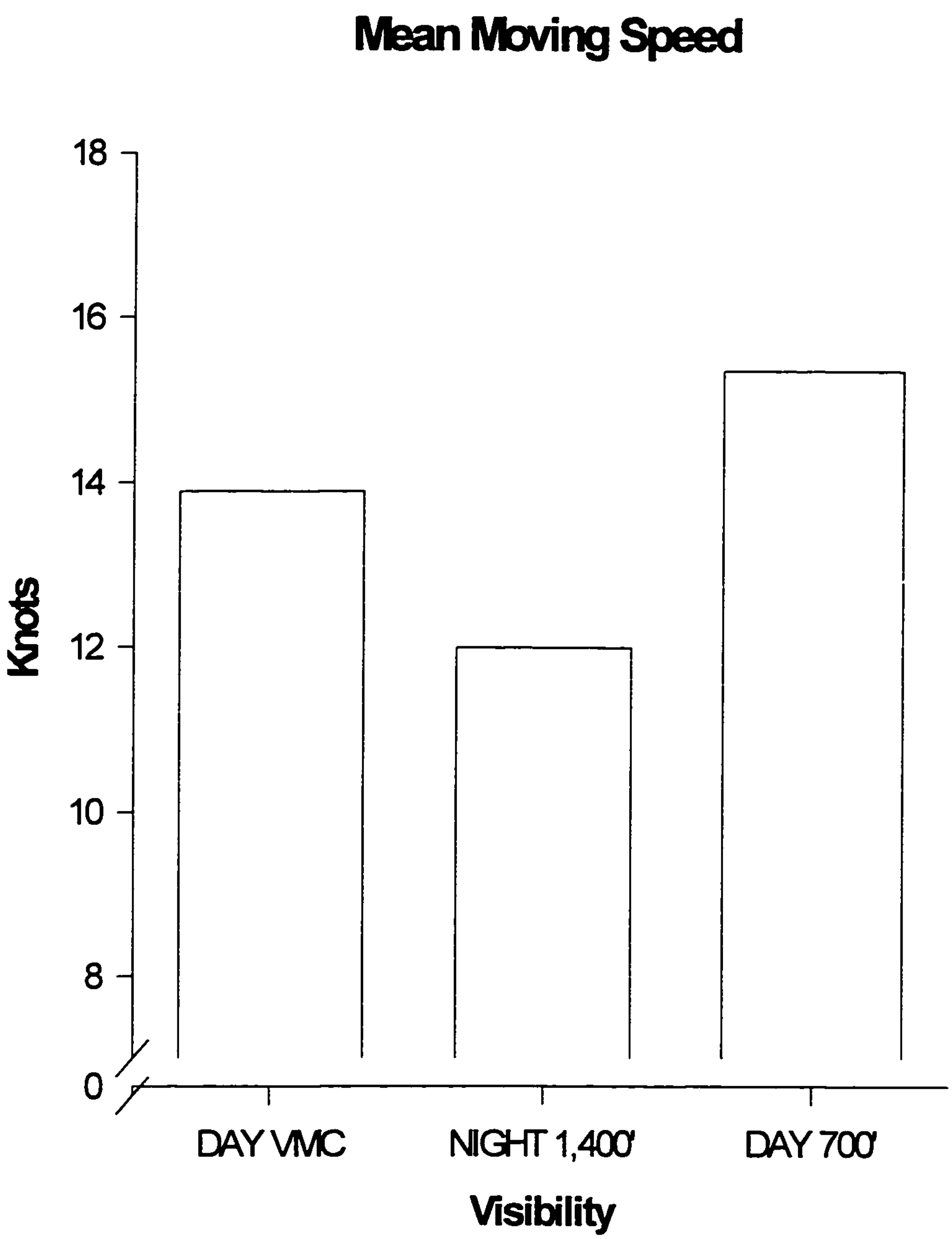


Figure 4. Means with Standard Error Bars for Mean Moving Speed.

Performance Data: Navigation errors

There were no main effects for either Visibility or Instructions, and no interaction of Visibility by Instructions.

Performance Data: Mean planning time

There was a main effect of Visibility, $F(2,20) = 7.15$, $p < .05$. Post hoc test of the visibility main effect showed that average planning time, the amount of time spent at the terminal before moving measured in seconds, was significantly shorter for Night 1,400' RVR (28.97 seconds) than for Day VMC (35.97 seconds) and Day 700' RVR (38.43 seconds). However, there was no significant difference between Day VMC and Day 700' RVR (see Figure 5 for a graph of the means and standard errors). There was no main effect for Instructions, nor an interaction of Visibility by Instructions.

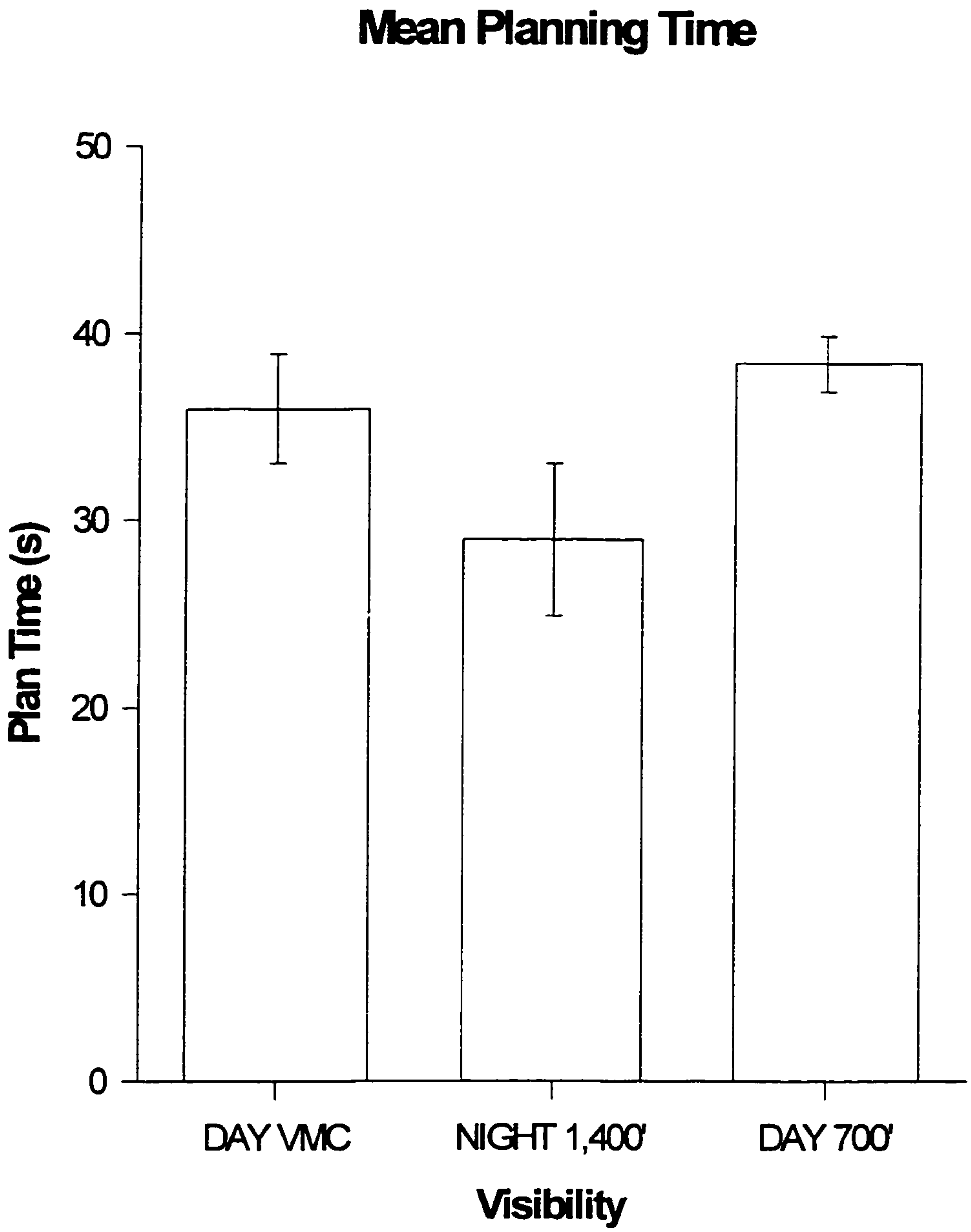


Figure 5. Means with Standard Error Bars for Mean Planning Time.

Performance Data: Map range level use

There are five map range levels that show the ownship's position on the airport surface. The higher map range level settings correspond to a tighter in zoom around the OS. Level 4x, tightest in zoom, displays 2,500' of airport surface in front of the OS, a width of 1,000' of airport surface at the OS icon, and a width of 2,500' at the top of the EMM. The lateral area displayed by the map at each zoom level increases as you look farther ahead of the OS icon due to the map's perspective design. As a result, the width of the airport surface displayed on the map at the top of the EMM is equidistant to the length of the airport surface displayed in front of the OS.

At 3x the map displays 4,400' in front of the OS icon, a width of 2,000' at the OS icon location and a width of 4,400' at the top of the display. At 2x, 7,000' is displayed in front of the OS icon, a width of 3,000' is displayed at the OS icon, and a width of 7,000' is displayed at the top of the display. At 1x, 9,000' is displayed in front of the OS icon, a width of 4,000' is displayed at the OS icon, and a width of 9,000' is displayed at the top of the map. Finally, OVR (overview) shows the entire airport in a 2-D perspective.

The means and standard deviations (SD) for percent time of trial each map range level was used are given in Table 1. The means show a preference for range 4x, but the large standard deviations tell us that range selection was idiosyncratic. It is also interesting to note that the mean speed when the map was set on overview (OVR) was 4.8 kts. In addition, the ground speed for 42 of the 57 instances when the EMM was set at OVR was below 1 kt.

Table 1

Mean Percent of Trial and Standard Deviations (SD) for Use of Each EMM Range Level

	Mean percent of trial	SD
ATIS	.07 %	.36 %
Overview	.56 %	1.24 %
Range 1x	2.35 %	9.04 %
Range 2x	10.12 %	24.19 %
Range 3x	30.38 %	37.79 %
Range 4x	56.51 %	41.41%

Performance Data: Incursions

Out of 24 incursion incidents, only six were responded to and of those six only four were responded to accurately. The average ownship speed at the time of the incursion incident was 17.2 kts with a standard deviation of 8.7 kts. The mean response time for the six incursions that were detected was 1.9 seconds with a standard deviation of .6 seconds.

During the verbal debrief the participants were queried as to whether or not the EMM helped them resolve the incursion incidents; the following are their responses:

- "It helped identify the incurring aircraft's orientation."
- "It helped direct visual attention out the window."
- "It helped identify potential threats."
- "It aided in a manner similar to TCAS."
- "It would help prevent runway incursions by clarifying where you were instructed to hold."

Eye Tracking Data: Percent time of trial dwelling on the EMM

There was a main effect of Visibility, F (2,20) = 3.96, $p < .05$. A post hoc test of the visibility main effect showed that percent time of trial dwelling on the EMM was significantly higher for Day VMC (41.3 %) than for Day 700' RVR (37.7 %), but not significantly higher than Night 1,400' RVR (39.4 %). There was no significant difference, however, between Day 700' RVR and Night 1,400' RVR (see Figure 6 for a graph of the means and standard errors). There was no main effect for Instructions, nor an interaction of Visibility by Instructions.

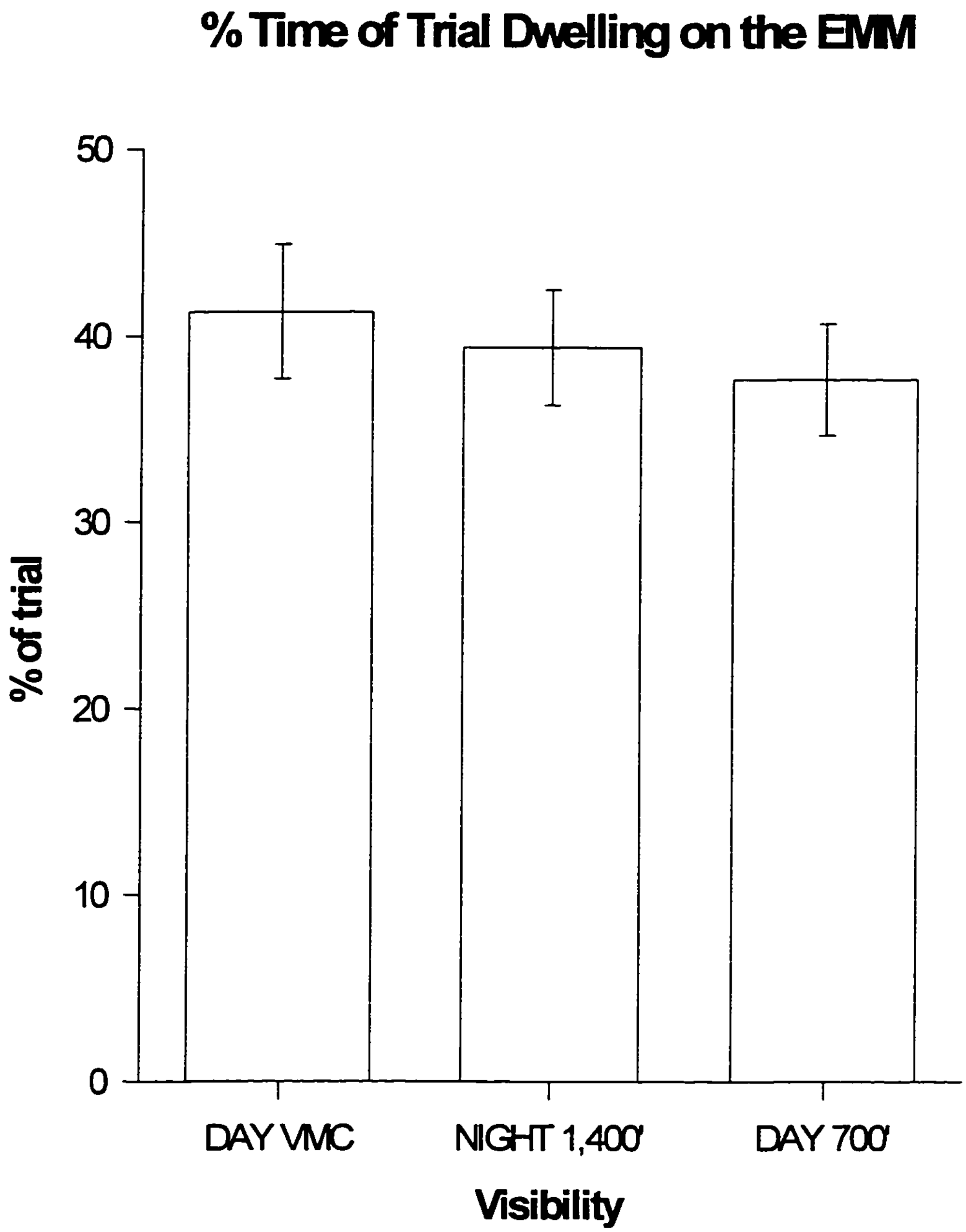


Figure 6. Means with Standard Error Bars for Percent Time of Trial Dwelling on the EMM.

Eye Tracking Data: Number of dwells on the EMM

There were no main effects for either Visibility or Instructions, and no interaction of Visibility by Instructions.

Eye Tracking Data: Mean dwell time

There was a main effect of dwell location (OTW vs. EMM), $F (1, 10) = 8.19, p < .05$. The average fixation time was longer when dwelling OTW (2.1 seconds) than when dwelling on the EMM (1.4 seconds). There was also a main effect of Instructions, $F (1, 10) = 5.65, p < .05$. The average OTW fixation time was longer for those participants that received EMM usage instructions (2.1 seconds) than for those that did not (1.4 seconds). Interactions were found for dwell location by Instructions, $F (1, 10) = 4.99, p < .05$, and Visibility by dwell location by Instructions, $F (2, 20) = 3.49, p < .05$.

A post hoc analysis on the dwell location by Instructions interaction revealed that receiving EMM usage instructions significantly increased average dwell time OTW. Post hoc analysis on the three-way interaction showed that in addition to EMM usage instructions significantly increasing average dwell time OTW, visibility significantly affected average dwell time on the EMM for the group that received EMM usage instructions. For the group that received EMM usage instructions, average dwell time on the EMM was significantly higher in Day VMC (1.5 seconds) than in both Day 700' RVR (1.4 seconds) and Night 1,400' RVR (1.4 seconds).

There was no main effect of Visibility, nor an interaction of Visibility by Dwell Location or Visibility by Instructions (see Figures 7a and 7b for graphs of the means and standard errors).

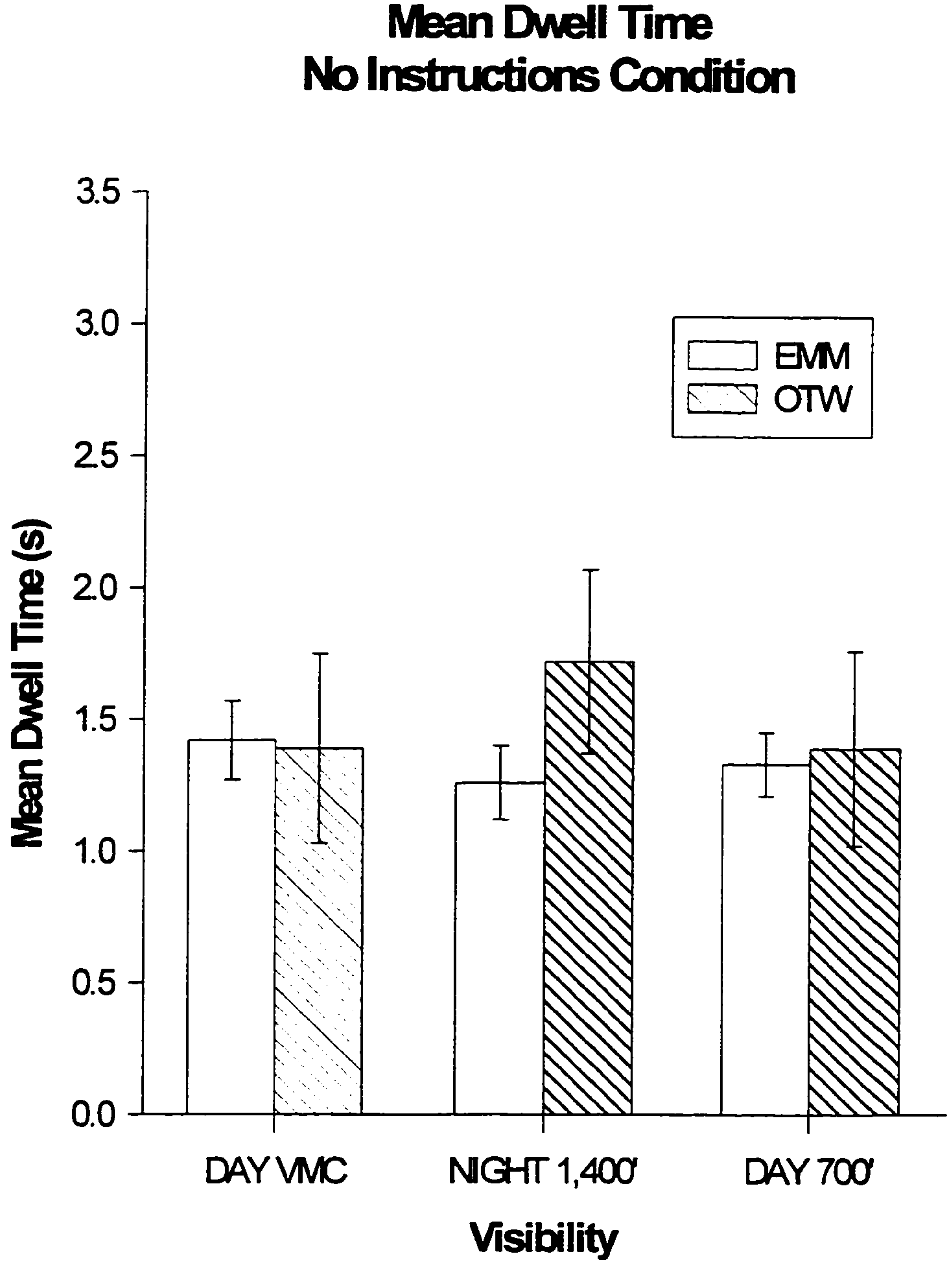


Figure 7a. Means with Standard Error Bars for No Instructions Condition Average Dwell Time.

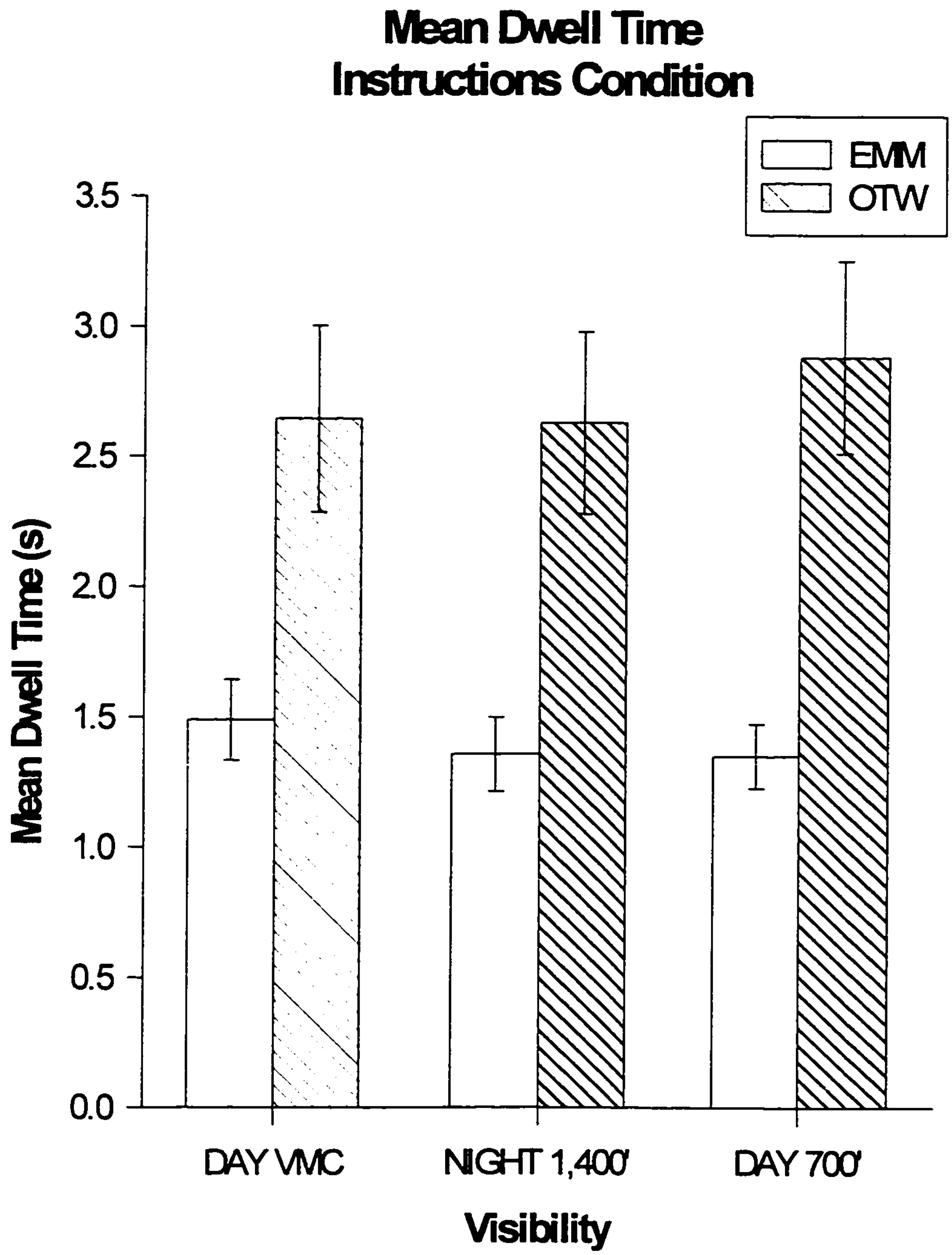


Figure 7b. Means with Standard Error Bars for Instructions Condition Average Dwell Time.

Survey Data: Route guidance

The participants were asked to rank the three route guidance versions with a ranking of 1 being "most favored" and 3 being "least favored", "Yellow" was the most favored. See Table 2 for route guidance rankings.

Table 2

Route Guidance Style Rankings

	Yellow	Disappear	Magenta
Rank 1	54 %	31 %	15 %
Rank 2	46 %	54 %	0 %
Rank 3	0 %	15 %	85 %

In the first survey, the participants were asked if they used the route guidance to plan the remainder of their cleared taxi route while holding. Nine answered "Yes." These nine participants were then asked to rate their ability to do so with each route guidance condition. The scale used was a five-point scale with 1 meaning "very easy," 3 meaning "neutral," and 5 meaning "very hard." "Yellow" and "Magenta" were tied for the most "very easy" ratings (see Table 3 for the distribution of ratings).

Table 3
Distribution of Ratings for Ability to Plan Route Using Each Style of Route Guidance

	Very easy 1	2	3	4	Very hard 5
Yellow	78 %	11 %	11 %	0 %	0 %
Disappear	22 %	0 %	22 %	22 %	33 %
Magenta	78 %	11 %	0 %	0 %	11 %

All of the participants were then asked to rate their ability to detect the hold bars with each route guidance condition using the same 5 point scale. "Yellow" and "Disappear" were tied for the most "very easy" ratings (see Table 4 for the distribution of ratings).

Table 4
Distribution of Ratings for Ability to Detect Hold Bars Using Each Style of Route Guidance

	Very easy 1	2	3	4	Very hard 5
Yellow	71 %	29 %	0 %	0 %	0 %
Disappear	71 %	14 %	7 %	7 %	0 %
Magenta	21 %	36 %	29 %	7 %	7 %

Survey Data: Heading bars

The participants were queried how often they used the heading bars in each of the two surveys. The first survey immediately followed nine trials in which the participants were not given any route changes or asked for any heading information. The second survey immediately followed a block of four trials of which two were route changes given in cardinal headings (North, South, East, and West). In the first survey, the participants were asked if they used the EMM to verify their heading while taxiing and 100% of the respondents answered "No". They were then asked how often they used the heading bars in each visibility condition. For Day VMC, all of respondents answered "never", in Day 700' RVR 86% said never, and in Night 1,400' RVR 93% said never.

In the second survey, the participants were asked to rate the usefulness of the heading bars for route changes given in cardinal headings. The scale used for rating the heading bars was a five point scale where 1 was "very useful", 3 was "neutral", and 5 was "not very useful". Seventy-seven percent found the heading bars to be "very useful" and the remaining 23% found them to be "not very useful".

When the participants were asked to identify whether they used heading bars, digital compass heading, or both to orient the aircraft in a general heading, 50% denoted using the heading bars, 29% denoted the digital compass heading, and 21% denoted using both.

When the participants were asked to rate the color coding scheme of the heading bars 33% responded that they liked it, 50% responded neutrally, and 17% responded that they did not like it.

Finally, when asked to rate the size of the heading bars 42% responded that they liked their size, 50% responded neutrally, and 8% responded that they did not like their size.

Survey Data: Map usage strategies

Participants were asked to rate how often they used the map display in each of the visibility conditions on a five-point scale. A value of 1 meant "very often", 3 was "neutral", and 5 meant "not at all". For Day VMC the participants' responses were mixed, but for Day 700' RVR and Night 1,400' RVR they clearly felt that they used the display "very often" or "often" (see Table 5 for the distribution of responses). From Table 5 one can see a trend of increased use of the display as visibility decreased. This is in opposition to the "percent of trial dwelling on the EMM" eye-tracking data which shows that the average percent time of a trial dwelling on the EMM decreases as visibility decreases. The distribution of survey responses may be due to the participants' heightened state of information processing while taxiing in low visibility.

Table 5

Distribution of Responses for Participants' Assessment of EMM Use by Visibility

	Very often 1	2	3	4	Not at all 5
Day VMC	36 %	21 %	36 %	7 %	0 %
Day 700' RVR	71 %	21 %	7 %	0 %	0 %
Night 1,400' RVR	57 %	14 %	29 %	0 %	0 %

Participants were also asked if they used the EMM to aid them in performing a set of actions which were deemed appropriate or inappropriate uses of the display. Whether an action was deemed appropriate or not was based on the display's philosophy that the EMM should support eyes-out taxi, not local guidance. Verifying the cleared route, ground speed, hold bars, heading, position on the airport surface, position relative to the cleared route, and monitoring traffic movements were all considered appropriate uses of the map. Using the display to assist turning the aircraft, track the centerline, or replace the OTW view were considered inappropriate uses of the display because these are local guidance tasks. The responses are given in percentages for all questions in Table 6. The breakdown of answers by instruction group to the incorrect examples of EMM usage is given in Table 7.

Table 6

Distribution of Responses to Correct and Incorrect Examples of EMM Usage

	Yes	No
Verify route	93 %	7 %
Verify ground speed	93 %	7 %
Verify hold bars	100 %	0 %
Verify heading	0 %	100 %
Verify position on airport surface	93 %	7 %
Verify position relative to the cleared route	100 %	0 %
Monitor traffic movement and identification tags	100 %	0 %
Assist turning the aircraft	80 %	20 %
Track the centerline	27 %	73 %
Replace the OTW view	27 %	73 %

Table 7

Number of Responses to Incorrect Examples of EMM Usage Broken Down by Instructions

	No Instructions		Instructions	
	Yes	No	Yes	No
Assist turning the aircraft	5	1	4	2
Track the centerline	3	3	0	6
Replace the OTW view	3	3	0	6

During the verbal debrief the participants were asked to discuss their strategy for using the display in each of the visibility conditions. The following are their responses:

- "Taxied eyes-out and used the EMM as a cross check."
- "To obtain a global view of the cleared route."
- "To gain situation awareness."
- "To confirm turns."
- "To plan ahead."
- "As a heading reference."
- "As a primary navigation display."

<u>Debrief Interview: "How would the EMM alter your scan pattern in everyday operations?"</u>

Responses to the question regarding how the EMM would alter one's scan pattern included the following:

- "Increase frequency of dwells in the cockpit due to the EMM's ease of use."
- "Increase frequency of dwells in the cockpit to scan the display for traffic movements."
- "Increase percent of time eyes are in the cockpit as visibility decreased."
- "It would increase eyes-in time and that would be negative."
- "It would increase eyes-out time."
- "The EMM would allow one crew member to stays eyes-out and one crew member eyes-in."
- "The display would add to the scan pattern."

Debrief Interview: "What role did the EMM fulfill?"

The following is a list of responses that participants mentioned when asked what role the display fulfilled in completing the taxi task:

- "It simplified a complex airport."
- "Provides the big picture."
- "Provides situation awareness."
- "It can be used as a primary navigation aid."
- "It can be used as a secondary navigation aid."
- "Gave the aircraft's position on the airport surface."
- "Helped visualize the airport's flow."
- "Provided a means for previewing radio calls."
- "Provided a heading reference."
- "Made route changes easier to deal with."
- "Aided distance judgments."
- "Clarified confusing intersections and pad areas."

Discussion

Performance Data: Percent time on route

The operational definition of "percent time on route" was the percent of the trial that the aircraft's landing gear was on the taxiway surface of the cleared route. Deviations into the grass or taxiways and runways that were not part of the cleared route were considered off route. In addition, the width of the taxiway was used to define "on route" for pad areas and runways. As a result, when pilots did not track the centerline onto the runway, but instead used the runway's entire length they were considered "off route". This explains why values of 100% were never recorded.

The main effect of visibility is most likely attributable to the participants taxiing more eyes-out as visibility decreased. As the visibility decreased it is safe to speculate that they concentrated harder OTW to control lateral and directional loop closure and read airport signage. This is in fact what we find when we look at the eye tracking data for percent time dwelling on the OTW environment. As the visibility decreased the percent time OTW increased from 58.7% in Day VMC to 60.5% in Night 1,400' RVR to 62.2% in Day 700' RVR. As a result the participants were more aware of lateral and directional loop closure violations, vigilant of airport signage, and had to concentrate harder on the taxi task due to the decreased visual range. The increased level of awareness and concentration resulted in fewer deviations from the cleared route.

More importantly though, these results are consistent with the earlier findings of McCann et al. (1996). McCann et al. using the same definition of on route, an earlier version of the current EMM, and the same simulator (minus the side windows), found a virtual elimination of route deviations in low visibility. We have also found a virtual elimination of route deviations with the lowest percent time on route being 97.5%. This helps confirm that the addition of the eye tracking apparatus and helmet did not affect the performance of the participants performing that task. As you will see below, other performance metrics and comparison to previous studies further support this statement.

Performance Data: Mean moving speed

The main effect found for visibility is a deceiving one that must be carefully interpreted. The decrease in average moving speed as visibility decreased to Night 1,400'

RVR was expected. However, the increase in taxi speed in the lowest visibility (Day 700' RVR) appears to be an anomaly, but one that can be explained by simulation artifacts and an increased percent time OTW.

In regards to simulation artifacts, the participants were only given two simulation cues as to their speed: throttle noise and visual flow. There were no kinesthetic cues as to the speed of the aircraft, for example seams in the taxiways or vestibular cues. These are two cues that participants stated they rely upon heavily while taxiing in the real world. They noted rarely using ground speed gauges and power settings to monitor ground speed as they try to stay eyes-out as much as possible. This leads to the next point. As visibility decreased they were more focused on the OTW environment and therefore had less opportunity to scan the ground speed indicator. This, in tandem with the lack of kinesthetic speed cues, would often result in their inability to continually monitor their ground speed resulting in faster ground speeds. At the end of the experimental trials it was not unusual for a participant to be apologetic for their high ground speeds and remark that they were surprised when they looked down and noticed how fast they were going.

One positive finding that we can take away from this analysis though is that the absolute speeds are consistent with earlier research. The mean absolute speed found in this experiment was 13.7 kts, consistent with the findings of McCann et al. (1996) and McCann et al. (1997). Again, the important point is that the eye tracking system did not affect average moving speed.

Performance Data: Navigation errors

As expected, the number of navigation errors per trial was almost non-existent, unquestionably due to the presence of the EMM. Once again, these findings are consistent with the findings of previous studies in the developmental history of the EMM display. Mejdal and Andre (1996) found a navigation error rate per route of .06; the current study found a navigation error rate per route of .06. McCann et al. (1997) found that the participants made an average of one navigation error over seven trials run in Day 700' RVR. This finding indicates that the eye tracking hardware had no effect on performance.

Performance Data: Mean planning time

The main effect of visibility in this analysis is somewhat perplexing. The increase in planning time from Day VMC (36 seconds) to Day 700' RVR (38.4 seconds) is logical, but the drastic drop in planning time for Night 1,400' RVR (29 seconds) was not expected. The only plausible explanation for this finding is that it is due to an anomaly in the data.

Once again we find that some of these results are similar to previous EMM research findings. McCann et al. (1996) found that mean planning time when using the EMM was 38 seconds in Day 700' RVR and 32 seconds in Day 1,400' RVR, a near match to findings of the current study.

Performance Data: Map range level use

As the means and standard deviations in the results section showed, the use of the map's range levels is idiosyncratic. The data does not indicate a clear preference for one particular range level over another, but tells us that each participant had a different strategy for using the display's range levels.

However, there is one consistent range-level usage trend. For the brief periods of time when the overview setting was active, it was active during planning time and periods when pilots were asked to hold mid-route. This is evident by the mean ground speed of 4.8 kts when the OVR setting was active. It is further bolstered by the fact that speeds under 1 kt were found for 42 of the 57 times the OVR setting was activated. This shows that pilots were using the North-up, fixed, overview mode to plan their routes or the remainder of their routes. These findings on range-level preference and overview mode usage trends are also consistent with work done on previous versions of the EMM by Mejdal and Andre (1996) and McCann et al. (1997).

Performance Data: Incursions

In interpreting the incursion data we must take into account three factors: the incursion detection response method, the direction of the incursion, and the tendency of the pilots to hold short before responding. As mentioned in the results section, only six out of 24 possible incursions were responded to, and only four of those were responded to accurately.

The first and second problems are intertwined, and are the result of the incursion detection response method based on an algorithm of time to impact and distance. The maximum allowable response time was three seconds, beginning the moment the incurring traffic icon began to flash red on the EMM. However, this time limit could be shortened depending upon time to impact and distance to the incursion point. The faster the ownship's speed, the earlier the alert went off and the shorter the amount of time to respond in order to avoid a ground collision. As a result, sometimes the alerting logic would trip before it looked like a piece of traffic could possibly be a threat, or even noticeable on the EMM if the 4x range setting was selected.

The other problem this created was that the incurring piece of traffic was not always approaching from the same side of the ownship's nose for each participant. This is important because a response was deemed correct by whether or not the pilot responded with the corresponding button on the tiller that matched the direction off the nose from which the incursion was approaching. The first incursion scenario had a left turn to a taxiway in advance of the impact point. If the participant pilot's aircraft was going fast enough, the incurring piece of traffic would be moving at it head-on but on a parallel taxiway to the left of the ownship's nose. As a result, the piece of traffic would not resemble a potential incursion. However, if the participant pilot's aircraft was going slower, the incurring piece of traffic would be approaching orthogonally from the right and pose a potential incursion threat. Thus, the alerting logic and incursion direction of travel were less than optimal ways for making sure that the participants realized that the incurring piece of traffic was a genuine threat.

The other main problem is that the participants' response sequence to seeing the alerting logic was to decrease speed, search the EMM and OTW scene for the incursion, and then respond. As a result, it is very likely that many of the incursions were detected, but not responded to within the time limits determined by the algorithm. This assertion is further supported by the interview responses listed in the results section which state that the display was helpful in identifying the incurring aircraft's orientation, directed visual attention OTW, and aided in identifying potential threats.

Summary: Performance data

In reviewing the above sections, it is apparent that we have not altered the participants' behavior by implementing an eye tracking methodology. All of the performance measures results were similar to the findings of previous studies on EMM's. Clearly then, the answer to the question, "Did the eye tracker affect the participants' behavior?" is "No", allowing further analysis and discussion. This finding increases our confidence in the eye tracking data analyses used for examining how different levels of visibility and training affect allocation of visual attention.

Eye Tracking Data: Percent time dwelling on the EMM

In comparing our findings to that of Battiste's (Battiste et al., 1996), our finding of 62% of total trial time heads-up and eyes-out in Day 700' RVR is similar to Battiste's finding of 65% of total trial time heads-up in Day 700' RVR. Despite using single pilots instead of crews, a part-task simulator instead of a full-mission simulator, and a different version of an EMM, pilot's heads-up, eyes-out time was unaffected.

A possible reason for finding that eyes-in time decreases as visibility decreases is that the pilots needed to be eyes-out to maintain lateral and directional loop closure, scan for hazards, and maintain information gathering OTW. This assertion is supported by the increased percent time on route.

The potential for pilots to use the display for aircraft control and to rely too heavily on the display in decreased visibility was a major concern and the primary reason for the study. The decrease in percent time on the EMM for both instruction groups as visibility lowered shows that participants were using the display as a secondary means to scanning the OTW environment to navigate and maintain situation awareness. This finding also shows that they were not using the EMM to control the aircraft as the visibility decreased. The results tell us that the EMM affords proper usage of the display as a secondary navigation aid.

Eye Tracking Data: Number of dwells on the EMM

A lack of a main effect or interaction for this measurement suggests that the number of times a participant dwelled on the EMM was idiosyncratic.

Despite not finding any significant main effects or interactions, we can look at the means and standard errors from the analysis and extract some usage patterns. The most interesting difference in means is the one found for the Instructions variable. The group that received no EMM usage instructions had a mean number of dwells on the EMM of 125 with a standard error of 19.9. The group that did receive EMM usage instructions had a mean of number of EMM dwells of 86.4 with a standard error of 19.9. While it did not result in a main effect of Instructions, it seems that the training given in the EMM usage packet was sufficient to alter the participants' behavior. It tells us that by providing training on the display we are able to impact the user's behavior so that they use the display as a secondary navigation aid to navigating eyes-out. When these data are viewed in combination with average dwell time, this, indeed, was found. The data show that the group receiving instructions spent more time scanning the OTW environment than the group that did not receive usage instructions.

The means for the Visibility variable also show a trend of increasing number of dwells on the EMM per trial as visibility decreases. The mean number of dwells for Day VMC is 94.1 with a standard error of 7.5, for Night 1,400' RVR is 109.8 with a standard error of 22.1, and 113.2 for Day 700' RVR with a standard error of 18.7. This shows that the participants were scanning the display more often as visibility decreased, but percent time of trial dwelling on the EMM decreased. Therefore, from these means it can be seen that participants who received the usage instructions scanned the display less often than those who did not, and that the pilots scanned the display more frequently in low visibility.

Eye Tracking Data: Mean dwell time

Among the results found for the analysis on average dwell time, the one of interest is the dwell location by Instructions interaction. Before discussing this interaction, it will be explained as to why the 3-way interaction of dwell location by Visibility by Instructions is not as important. From the analysis on Visibility and its interactions with either Dwell Location or Instructions, it was found that it did not reach significance, but it did in the 3-way interaction. The presence of the 3-way interaction is most likely due to an anomaly in the data that brought visibility to significance only in this 3-way interaction. Therefore we feel that the interaction of interest is the 2-way interaction of dwell location by Instructions.

The dwell location by Instruction interaction shows that the main effects found for dwell location and Instructions are due to the OTW average dwell time for the group receiving EMM usage instructions. The average dwell time OTW for the group that received usage instructions is significantly higher than the group that did not receive instructions, and higher than the average dwell time on the EMM for both groups. This means that providing instructions on EMM usage alters user behavior by increasing average dwell time OTW. It is also congruent with the lower average number of dwells OTW and higher percent time of trial dwelling OTW for the group that did receive usage instructions.

Another area of these results that merits discussion is the non-homogeneity of variance. The increase in standard error for average dwell time from the EMM to OTW for the group that received EMM usage instructions may be due to the nature of the data. Search time data is akin to reaction time data where there is a minimum speed at which one can react to, or search for, a stimulus. This minimum value is where most of the data points lie and with decreasing numbers of points as reaction and search times lengthen, resulting in a positively skewed distribution known as a Poisson distribution. This is the typical distribution of reaction time and visual search time data and therefore the non-homogeneity of variance is not of concern, but instead is expected.

Finally, we should also note that once again results were consistent with Battiste et al.'s (1996) results. Battiste et al. found that the average dwell time on the EMM was 1.25 seconds. In our study, we found the average dwell time on our EMM was 1.37 seconds. As mentioned above, this shows that our methods and apparatus did not alter the participants' behavior taxiing.

Summary: Eye tracking data

In comparing the results of the eye tracking data analyses to the hypotheses, we find that for the most part the results were in accordance with the hypotheses. In regards to percent of trial dwelling on the EMM, we had predicted that the percentage would increase as visibility decreased. This was the one case in which the hypothesis was completely wrong. Instead we found that the percent time of the trial dwelling on the EMM actually decreased. As for Instructions, we had predicted that the group that received training on EMM usage would have a lower percent time of trial dwelling on the EMM than the group not receiving EMM usage training. We failed to achieve significance, but a trend emerges that suggests the hypothesis was appropriate.

The analysis on number of dwells on the EMM failed to achieve significance for both Visibility and Instructions. It was predicted that the number of dwells on the EMM would increase as the visibility decreased. It was also predicted that the number of dwells on the EMM would be lower for those participants that received EMM usage instructions. Despite failing to achieve significance, trends suggests the hypotheses were valid.

Finally, the analysis of the eye tracking data for mean dwell duration partially supported its corresponding hypotheses. We had hypothesized that dwell duration on the EMM would increase and dwell duration OTW would decrease as the visibility decreased. Instead we found that dwell duration on both the EMM and OTW stayed constant throughout all three visibility conditions. However, for the Instructions manipulation, it was hypothesized that the group that received EMM usage instructions would have a lower mean dwell time on the EMM and higher mean dwell time OTW than their counterparts. This hypothesis was only partially supported. The mean dwell time on the EMM for the two groups was similar, but the mean dwell time OTW was significantly higher for the participants that received EMM usage instructions.

In summary, the eye tracking data allowed for the accurate assessment of the visual attention allocation predictions. The trends and significant results obtained supported the initial hypothesis; that pilots without usage instructions are inclined to visually attend to the EMM more than pilots provided usage instructions (training). This objective data is further supported by the subjective data discussed next, but in some cases we find that the subjective data is not congruent with the objective data. In particular, the subjective data for assessment of EMM use by visibility is not consistent with the eye tracking data for percent time of trial dwelling on the EMM.

Survey Data: Route guidance

The yellow route guidance version was ranked as "most favored" in the ratings, and was tied for first for ability to detect hold bars and to plan the remainder of the route. From the results, it is clear that route guidance version "Yellow" is the style that should be implemented in future iterations of the EMM.

Survey Data: Heading bars

The important message from the analysis of the survey data concerning hold bars is that they are useful but only for times when clearances, route changes, or other instructions are given using cardinal headings. We found from the survey data that nobody verified their heading or used the heading bars during the first nine trials. These first nine trials were trials in which no cardinal heading based instructions were given. However, the survey responses dramatically changed for the second survey. The second survey followed a block of four trials in which two of the trials were mid-route route changes using cardinal headings. In the second survey, 77% of the participants noted the heading bars as being "very useful". This shows that for the trials involving cardinal heading-based instruction, the heading bars were used for orienting and verifying heading.

This is further confirmed by another question on the second survey which asks about whether the participants used the digital compass, compass bars, or both to navigate the mid-route route changes. The responses to this question yielded that 71% marked either compass bars or both. Therefore, we can assume that the heading bars are a functional part of the display and are being used when the need arises. However, the participants were not completely satisfied with the heading bars' design, specifically the color-coding and size. Therefore, the heading bars are a useful map feature, but need to be redesigned to allow optimal use. Possible redesigns include making them a solid color, increasing the font size, and adding labels for Northwest, Northeast, Southwest, and Southeast.

Survey Data: Map usage strategies

From the survey data, we found that participants felt they were using the display more often as the visibility decreased. This is in contradiction, however, to the percent time on the EMM data that was gathered by the eye tracker. The eye tracking data shows that percent time on the EMM decreases as the visibility decreases. One plausible explanation for this contradiction is that the survey responses may reflect the amount of cognitive attention dedicated to processing foveal vision.

For example, everyone has had the experience of reading a paragraph and then realizing that we did not process one word of information because we were distracted or tired. The same applies to the EMM display except that it is not a function of distraction or alertness, but instead a function of the need to process the information. In Day VMC, the pilots can maintain situation awareness, lateral and directional loop closure, and navigate eyes-out without taxing cognitive attention. Therefore, when they scan the map display, the level of processing is shallow because they have the necessary information available OTW. However, as visibility decreased, the participants made more frequent dwells on the map for shorter periods of time, and for a smaller percent of overall time. During these more frequent, brief dwells, the participants were likely scanning the display with the purpose of extracting particular bits of information. Due to the decreased visibility, the information necessary to support their taxiing was not available OTW so it had to be acquired and processed from the EMM. Subsequently, the participants' need for, and benefit from, the EMM was higher under low visibility and they therefore recalled using the display more as visibility decreased. In light of this interpretation of the results, these findings are not that surprising and show proper and intended use of the display.

Another question on the survey asked the participants to denote whether or not they used the display to perform actions the display was either intended or not intended to support. Almost all of the participants noted using the display to support actions that the display was intended to support. However, when it came to actions that the display was not intended to support we found a difference between those that did and did not receive EMM usage instructions.

Specifically, we are interested in whether or not the participants used the display to assist turning the aircraft, track the centerline, and replace the OTW view. We found that for the group which received EMM usage instructions, none of them reported using the display to track the taxiway centerline or replace the OTW view, but four of the six did note using the display to assist turning the aircraft. The finding that participants who did receive EMM usage instructions used the display to assist turning the aircraft could be due to a lack of clarity in the question. It was intended to ask if the display was used to control the aircraft while performing turns, that is, to stay on the centerline or within the confines of the taxiway. However, it seems likely that the question was interpreted as meaning several things; for example, identifying the correct taxiway centerline to turn onto, pre-planning a turn, or confirming a turn. Therefore, it is possible that the responses are not a reflection of the question's original intent. This seems likely since none of the participants from the group that received the EMM usage instructions reported using the display to track the centerline or replace the OTW view.

The distribution of the data for the group that did not receive instructions is also interesting: Approximately half of the participants from the group that did not receive EMM usage instructions reported that they used the display for tracking the centerline or replacing the OTW view. This tells us that without training, pilots are prone to misuse the display. However, the fact that some of the participants from the group that did not receive EMM usage instructions did not report using the display for centerline tracking or replacing the OTW view is encouraging. This implies that the display's design aids its proper usage as a secondary navigation aid. The main point to be extracted though is that training is necessary and development of usage procedures vital.

From the verbal debrief, we find that participants were for the most part using the display properly and for the purposes it was intended. It appears that they were using the display as navigation tool, a crosscheck, and to gain situation awareness, and not as a method for controlling the aircraft. This both reconfirms the survey data and supports the assertion that the display's design affords its proper use.

Debrief Interview: "How would the EMM alter your scan pattern in everyday operations?"

Most of the responses suggested that the display would increase frequency of dwells in the cockpit and/or eyes-in time. These responses were because the pilots felt the EMM was easier to use and provided more information than the paper charts that are currently used. The pilots also noted a concern that the increase in eyes-in time and number of dwells on the EMM would have a negative effect. Without eye tracking data on percent time eyes-in, number of dwells, and average dwell time for taxiing with paper charts, it is hard to tell whether or not these responses would be supported by the data. However, if we compare the findings from this study and Battiste et al. (1996) we find that our results for EMM-related data are similar and therefore we might be able to draw comparisons to his work.

The data from the current study show that the aforementioned responses are not reported as visibility decreased. While the mean number of dwells on the EMM did increase as the visibility decreased, there was no main effect of visibility. The data on percent time dwelling on the EMM and average dwell time on the EMM decreased as the visibility decreased. Therefore, if pilots are concerned that this display would negatively affect the scan pattern, the data on its use do not support this concern. Instead the eye tracking data shows that the pilots are more apt to dwell OTW and use the display more efficiently as visibility decreases. In addition, we know from previous studies (Foyle et al., 1996; McCann et al., 1997; McCann et al., 1996; ; Mejdal & Andre, 1996; Tu & Andre, 1996) that this display increases taxi performance as measured by incursion detection, navigation errors, and overall taxi time. Therefore, the pilots' responses are likely the result of increased information processing of the EMM as visibility decreases.

Debrief Interview: "What role did the EMM fulfill?"

From the responses it is clear that the participants felt the EMM fulfilled its intended role as a secondary navigation tool. The pilots noted that the EMM acted as a secondary navigation tool, a means for seeing the big picture, providing situation awareness, easing route changes, and simplifying complex airports. Most notably though is the absence of responses that suggested the display fulfilled the role of a means for controlling the aircraft or replacing eyes-out navigation as the primary navigation method. This once again reconfirms that the display's design and features promote proper use of the display as a secondary navigation aid to eyes-out taxiing.

General Summary

In reviewing the data and interpreting the results it was found that not all of the hypotheses were supported, but in general the results were positive. The first area of note is the performance measures. For each performance measure, it was repeatedly found that the addition of the eye tracking apparatus did not alter the participant's behavior in comparison to previous studies on the T-NASA system and EMM. This increases our confidence that the eye tracking data collected is veridical and not an anomaly produced by the methodology of the experiment.

The eye tracking data is also positive and consistent with the EMM's design philosophy, despite some unexpected findings. For example, it was hypothesized that percent time eyes-in would increase as visibility decreased, but this was not found. Instead, it was found that it decreased as visibility decreased. This is positive because it shows that the pilots are not using the display for aircraft control or as a primary navigation aid, but instead as a secondary navigation and situation awareness aid. The findings for average dwell time also support this assertion in that average dwell time OTW for the group that received EMM usage instructions increased as visibility decreased.

The main point to be taken from the results when analyzed by visibility is that as visibility decreased so did allocation of visual attention to the EMM. Therefore, the pilots did not become dependent on the display for taxiing in low visibility, but instead increased their eyes-out time and used the EMM more efficiently.

In reviewing the eye tracking data as a function of the Instructions manipulation the same general theme is found. While Instructions only reached significance for average dwell time, a difference between the two groups was noticeable and might have reached significance for other measures if more participants were tested. For example, the average percent time eyes-in for the group that did not receive usage instructions was 44% of a trial, while it was 35% for the group that did receive usage instructions. We also find a large difference between groups in regards to number of dwells on the display. The group that did not receive usage instructions dwelled on the EMM an average of 125 times per trial, while that average was 86 times for the group that did receive usage instructions. These figures show that those who did receive EMM usage instructions used the display in accordance with the philosophy behind it. It also shows that training had an effect because there are differences between the two groups. However, the data also show that there were some people who did not receive training that did use the display correctly. While this is a testament to the EMM's design, we cannot discard the data that suggests training is crucial.

The interview and survey data regarding usage strategy and role of the EMM were further support for the assertion that the display will not alter heads-up eyes-out time in a negative fashion. In terms of survey data, one can focus on the questions in which the participants were asked to note whether or not they used the display to do actions that the display was not intended to support. When these responses are analyzed separately for the two instructions groups, it is found that none of the participants in the group that received EMM usage instructions used the display incorrectly. However, half of the participants from the group that did not receive EMM usage instructions gave responses that showed they did not use the map properly. This reemphasizes the importance of training and the need to develop EMM usage procedures.

When we review the interview responses it is clear that the participants felt the display was meant to be a supplement to taxiing eyes-out and a cross-check to what they were seeing out the window. For example, when the participants were asked to describe their strategy for using the display, only one person responded that they used the display as their primary means of navigation. The other participants responded to the display in a manner that supported global awareness, not local guidance. This was reconfirmed when the participants were asked what role the display fulfilled. Once again, there was only one response indicating that the display fulfilled the role of a primary navigation aid. The remainder of the responses stated that the display fulfilled the role of a global awareness tool. From both the survey and interview data it is clear that the participants were using the display as a secondary navigation aid to support the global awareness components of taxiing, not the local guidance aspects.

In regards to design of the display, we may conclude that the "Yellow" route guidance version was preferred over the other styles of route guidance. As a result, it will be incorporated in future versions of the display. The responses to the heading bar questions were positive, and the heading bars should remain on the map, but be redesigned as suggested earlier. In addition, pilot feedback was positive in regards to the display's overall design and presentation. They felt that it was easy to use, clear, and supported their needs.

Switching from a micro-analysis level to a macro-analysis level, it becomes apparent that the EMM is capable of increasing airport throughput in low visibility while not compromising safety and allocation of visual attention. The data show performance levels consistent with previous EMM studies in tandem with an increase in visual attention OTW; importantly pilots stated that they felt they were using the EMM more as visibility decreased. In essence, the results tell us that using an EMM is a win-win situation because airport throughput in low visibility will only increase and the display aids situation awareness without violating proper usage.

Future Research

While the results from this study were encouraging, we need to continue to study the effects of visibility and weather, training and procedural issues, and situation awareness. Work needs to be done that not only focuses on daytime low visibility, but also varying times of day, weather conditions, and visibility levels, including clear, high visibility days and nights to see how visual attention is allocated in all conditions. Crews, instead of single pilots, need to be used in future experiments to verify that the results obtained in this experiment are not an artifact of the absence of another crew member or tasks that normally arise during taxi. Different regimes of training need to be tested in tandem with procedural issues to establish minimums for training. More research needs to be done on situation awareness and hazard detection comparing participants using EMM's to those using Jeppesen charts to validate pilot feedback that the EMM helps hazard detection and decreases incursions. Finally, to be sure that the results we found are not due to the display's novelty, pilots that have already seen and used the display need to be tested.

Conclusion

In closing, this study was a preliminary assessment of pilot visual attention while using an EMM for taxiing in various visibility conditions and levels of training. The data from the current study suggests that implementing Electronic Moving Map displays for low-visibility surface operations will not have a negative impact on allocation of visual attention in low- or high-visibility conditions. The data also suggests that training is necessary to assure proper usage of an EMM in daily operations. This study has been an informative and positive beginning to a series of studies that need to be conducted to fully understand the allocation of visual attention in varying levels of visibility while using an EMM. It has also been an insightful first step in investigating the effects of training on EMM use.

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Appendix A. Signed Approval Form

San José State
UNIVERSITY

Office of the Academic Vice President

Associate Vice President Graduate Studies and Research

One Washington Square
San José, CA 95192-0025
Voice: 408-924-2480
Fax: 408-924-2477
E-mail: gstudies@wahoo.sjsu.edu
http://www.sjsu.edu

TO: David A. Graeber
120 Lowell Ave.
Palo Alto, CA 94301

FROM: Serena W. Stanford
AAVP, Graduate Studies & Research

DATE: November 21, 1997

The Human Subjects-Institutional Review Board has approved your request to use human subjects in the study entitled:

"Assessing Visual Attention of Pilots in the use of Electronic Moving Map Displays"

This approval is contingent upon the subjects participating in your research project being appropriately protected from risk. This includes the protection of the anonymity of the subjects' identity when they participate in your research project, and with regard to any and all data that may be collected from the subjects. The Board's approval includes continued monitoring of your research by the Board to assure that the subjects are being adequately and properly protected from such risks. If at any time a subject becomes injured or complains of injury, you must notify Serena Stanford, Ph.D., immediately. Injury includes but is not limited to bodily harm, psychological trauma and release of potentially damaging personal information.

Please also be advised that all subjects need to be fully informed and aware that their participation in your research project is voluntary, and that he or she may withdraw from the project at any time. Further, a subject's participation, refusal to participate, or withdrawal will not affect any services the subject is receiving or will receive at the institution in which the research is being conducted.

If you have any questions, please contact me at (408) 924-2480.

Appendix B. Consent Form

AGREEMENT TO PARTICIPATE IN RESEARCH AT SAN JOSE STATE UNIVERSITY

Responsible Investigator: Tony Andre, Professor, and Dave Graeber

I have been invited to participate in research on the visual attention of pilots using an electronic moving map (EMM) display. The possible benefits I might gain from my participation include learning more about how an EMM affects pilot behavior and visual attention. The possible risk is minimal eye strain equivalent to what might occur from 1 hours work on a computer. I understand that my participation in the experiment is voluntary.

If I decide to participate, I will be asked to taxi an aircraft, while wearing an eyetracking helmet, in a high fidelity part task simulator for 12 trials. The 12 trials will be broken into two blocks of 6 trials, each block should last no more than 30 minutes. Between the two blocks of trials a twenty minute break will be given; the entire procedure should take 1 hour and 20 minutes.

Data gathered from this study will be stored on a computer disk which no one but the experimenter will be able to access. In case the results of this study are published, any information that is obtained from me in connection with this study and that can be identified with me will remain confidential.

My decision to participate or not participate will not in any way prejudice my future relations with San Jose State University. If I decide to participate, I am free to withdraw my consent and to discontinue my participation at any time without penalty.

If I have any questions, I may ask them prior to the start of the experiment. If I have any questions after the experiment, I may contact Dr. Andre at 408-342-9050 or Dave Graeber at 650-604-3291. If I have any complaints about the procedure, I may contact Dr. Robert Cooper, Psychology Department Chair at 924-5600 (DMH 157). For questions about research participants' rights, or in the event of research-related injury, I may contact Dr. Serena Stanford (Associate Academic Vice President for Graduate Studies) at 924-2480.

I am making a decision whether or not to participate. My signature indicates that I have decided to participate having read the information provided above. I have received a copy of this consent form for my records.

DATE______________

SIGNATURE__________________________

PRINTED NAME_______________________

SOCIAL SECURITY #__________________

SIGNATURE__________________________(Investigator)

Appendix C. Demographics Form

DEMOGRAPHIC SURVEY

Name ________________ Subject # ____________

1. Current Crew Position (circle one): Captain First Officer

2. Current Aircraft (specific make, model, version)____________________

3. Is your aircraft equipped with an EFIS (glass) cockpit (circle one)? YES NO

4. Approximately how many hours have you logged at your current position in your current aircraft?

____

6. Approximately how many hours have you logged in the B737? __________

7. How many hours have you logged in a simulator? ________

8. How many hours have you logged performing ground taxi in a simulator?

______

9. Have you ever flown as a flight deck crew member into or out of Chicago O'Hare airport?
Yes_____ No______
If yes:
How familiar are you with the O'Hare airport layout?
Very ______ Moderately_____ Slightly______
Your experience in control of the aircraft while taxiing O'Hare is:
______not very experienced _____moderately experienced ______very experienced

Your experience in control of the aircraft while taxiing at O'Hare at **night** is:
______not very experienced _____moderately experienced ______very experienced

Your experience in control of the aircraft while taxiing at O'Hare in **low visibility** is
______not very experienced _____moderately experienced ______very experienced

10. How many hours experience do you have in:
Glass Cockpits ______ hours
Traditional Cockpits ________hours

11. Have you ever used an Electronic Map Display for Ground Navigation?(including cars) _____yes_____no.

If yes, Type if known: ________ Hours used: ______ Aircraft________ Vehicle___________

12. Do you wear reading glasses or contacts? ______yes______no

13. Age ________

14. Do you have a form of color blindness or color vision deficiency? ______yes______no

15. Your overall experience in control of the aircraft while taxiing is:
______not very experienced _____moderately experienced ______very experienced

16. Your overall experience in control of the aircraft while taxiing at **night** is:
______not very experienced _____moderately experienced ______very experienced

17. Your overall experience in control of the aircraft while taxiing in **low visibility** is
______not very experienced _____moderately experienced ______very experienced

Appendix D. General Instructions

General Instructions

First, we would like to extend our sincere appreciation to you for participating in this study. Your efforts will be instrumental in helping us assess the usefulness of our Electronic Moving Map (EMM) display, an electronic navigation aid to help pilots efficiently and safely taxi the airport surface.

Background to the study

The EMM was developed as part of the Taxiway Navigation And Situation Awareness (T-NASA) display suite under the auspices of Terminal Area Productivity (TAP), a major NASA program whose goal is to safely increase the traffic-handling capacity of existing airports. TAP encompasses a wide range of operational and technological initiatives, including reducing aircraft separation, creating a more efficient air traffic management system in the terminal area, and improving the efficiency of low visibility landing and surface operations. For example, the goal of our segment of the program is to develop flight deck aids that allow pilots to maintain VMC levels of taxi performance in IMC conditions.

To test the utility of the display we created a part-task simulation facility of Chicago-O'Hare airport, rear projected onto a wide screen. While inside the simulation environment, we ask you to assume the role of the captain of a commercial airliner with passengers on board. On each of the thirteen 'trials', we ask that you guide your aircraft from just outside a gate to a runway departure point as quickly, accurately, and safely as you deem fit. You will be taxiing under various levels of visibility (700'RVR, 1400'RVR or VMC) and during various times of day (day or night).

Procedure

The first thing you will do is participate in a practice period designed to familiarize you with the handling characteristics of the simulator, the EMM, and the EMM's input devices. Once you feel comfortable with the controls the eye-tracking device will be fitted and calibrated. Then, the experiment proper will begin.

Each route begins with a datalink clearance presented on the bottom two inches of the EMM (you will become familiar with this display during the practice session). The experimenter, playing the role of an air traffic controller, will also provide the clearance verbally through an intercom at the start of each trial. You should then follow the cleared route to the designated runway as quickly, accurately, and safely as you can. Once you have reached the runway departure point, the screen will go blank, and the clearance for the next route (trial) will soon appear. The study will be run in two segments with a survey after each block. The first block consists of 9 trials with rest breaks when requested. The second block is made up of four trials and there will be no breaks between trials.

Throughout the study, your goals should be to:

- Taxi as fast as possible, but with the operational constraints typical of a B-737 and with passenger comfort and safety in mind.
- Keep your aircraft at the center of the taxiway or runway as much as possible.
- Stay on the ATC cleared route at all times.
- Try to complete each route in as short a time as possible.

More details on procedure:

- Never guess the direction of a turn. Always attempt to follow the cleared route as closely as possible. If you get lost, check with ATC via the microphone on your headset.
- There are a number of inconsistencies between our departure scenarios and the real world. The primary differences are the general absence of other runway traffic, and the associated absence of background ATC communications. However, to try and minimize the 'video game' quality of the experience, we have programmed occasional, unexpected incursions by other aircraft. Please be on the alert for these incursions at all times. If you collide with the other aircraft, the screen will flash two or three times to indicate the collision. If this happens, the trial will terminate.
- Incursions are traffic that are within an designated area and travelling in a certain direction so that they might lead to an accident. These incursions may or may not happen though while you are participating in the experiment.

Limitations of the Simulation Facility

The vehicle model approximates the handling characteristics of a Boeing 737. However, you will be the only crewmember and you will quickly notice the absence of aircraft motion. We beg your indulgence for these limitations! Some of the simulator limitations are by design, while others are constraints of the simulation environment. Once again, we greatly appreciate your participation in this simulation. Please inform the experimenter that you are now ready to proceed.

Appendix E. Map Feature Instructions

Map Feature Instructions

There are several components that comprise the Electronic Moving Map (EMM) display. In the following section the main features will be briefly discussed, a chance to become more familiar with them will be given during a practice period.

- **Track-up orientation**: The EMM is a track-up rotating map. In other words it is not fixed in a North-up orientation, but instead it rotates in sync with you as you navigate the airport surface. It should be noted here though that the inset and overview modes are fixed in a North-up orientation.
- **Compass Bars / Heading**: The EMM provides two heading cues. The first cue is the heading bars that frame the EMM. These heading bars are color coded (North is gray, South is green, East is blue, and West is brown), labeled N, S, E, & W, and rotate as a result of the map being track-up. The purpose of these heading bars is to orient you when clearances are given using cardinal headings (e.g. "Turn south on Tango"). There is also a digital compass heading readout that is permanently displayed on the top center of the map (See figure 1).
- **Ownship (OS) Icon**: The OS icon is a white triangle with the apex representing the nose of the aircraft (See figure 1).
- **Wedge**: The wedge represents the area of interest in front of the aircraft and extends 1,250'. (See figure 1).
- **Traffic**: White moving and stationary aircraft icons represent traffic and are updated in real time. During an incursion the incurring piece of traffic's icon will turn red and begin to flash.

- **Traffic Tags**: The traffic tags display flight number and aircraft type, for example, DAL109/B737 (See figure 1).
- **Hold Bars**: These are yellow bars that appear in front of the aircraft, either the OS icon or traffic icon, that is NOT cleared to cross through the intersection where the incursion is predicted. If the yellow hold bar is in front of the OS icon you are to hold short and let the traffic pass through the intersection. The same hold bars are displayed on the map for mid-route holds as designated by ATC in the original route clearance. Once a hold bar is removed you are cleared to cross through that intersection (See figure 2).
- **Range Indicator**: In the lower right hand corner of the graphical portion of the EMM display is a range level indicator. The color red (See figure 1) denotes the zoom level that is currently being used.
- **Text box**: The route clearance is presented in the text box that comprises the bottom 2" of the display. The box is divided into 4 columns and should be read from top to bottom within each column and from left to right between columns. The textual clearance will also be colored magenta, same color as the graphical route guidance, and flanked by <<Alpha>> to designate the leg of the cleared route you are currently on. In the above example, <<Alpha>> would be colored magenta to show that your are currently on the "Alpha" segment of the cleared taxi route. When you are not on the cleared taxi route the text will be displayed as white and the << >> symbols will not be present. Across the top of the columns the starting and end points are displayed, for example " Concourse C to Runway 32L" (See figure 1).

- **Inset**: When the inset is activated it will appear in the lower right corner of the graphical portion of the map. It is presented in a 2-D, North-up orientation and cross hairs are provided to facilitate finding the OS icon. The inset provides an overview of the airport and cleared taxi route displayed in magenta (See figure 3).
- **Route Guidance**: The cleared taxi route is represented on the EMM as a thick magenta line. The graphical representation of the cleared route matches exactly to the verbal and data link route clearance. In this experiment we will be using three different versions of route guidance beyond the hold bars. The first version displays the magenta route guidance beyond the hold bar. The second version turns the magenta route guidance yellow beyond the hold bars. The third version hides the magenta route guidance beyond the hold bar (See figure 1).
- **Ground speed**: The ground speed of your aircraft is displayed in a small box in the upper left-hand corner of the map display (See figure 1).
- **Taxi ATIS page**: One of the range level options for the display is a taxi ATIS page. The page provides information regarding winds, visibility, temperature and dew point, altimeter setting, communication frequencies, pilot reports, and advisories (See figure 5).
- **Taxiway labels**: Taxiway labels are strategically placed on the map for optimal use while keeping clutter to a minimum. You will notice that as you change zoom levels the number of taxiway labels change. In the overview mode there are only labels for major taxiways displayed, and the inset has no labels. These labels are also presented

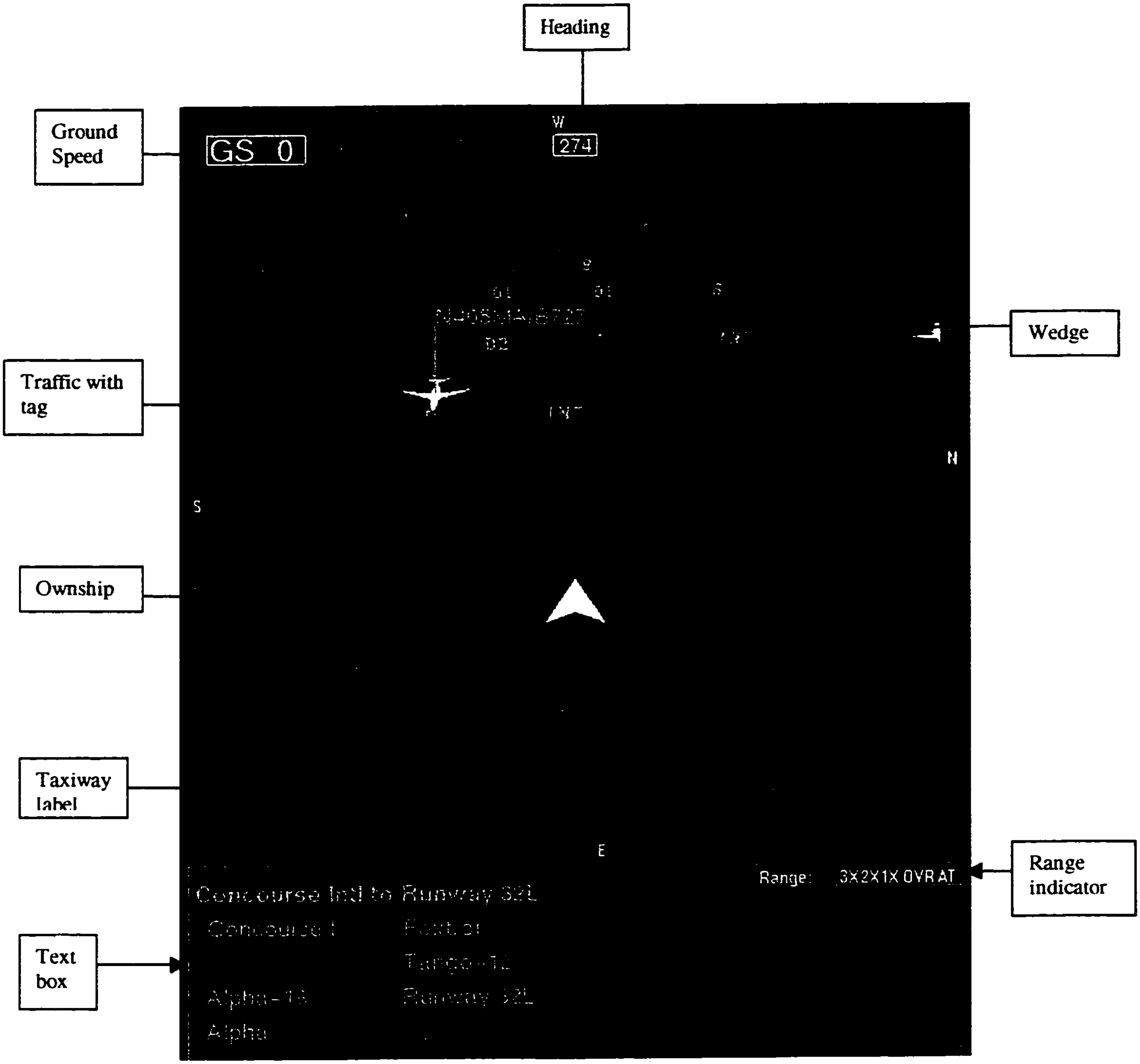

Figure 1: Heading, ownship icon, wedge, traffic with tags, range level indicator, text box, route guidance, ground speed, taxiway labels.

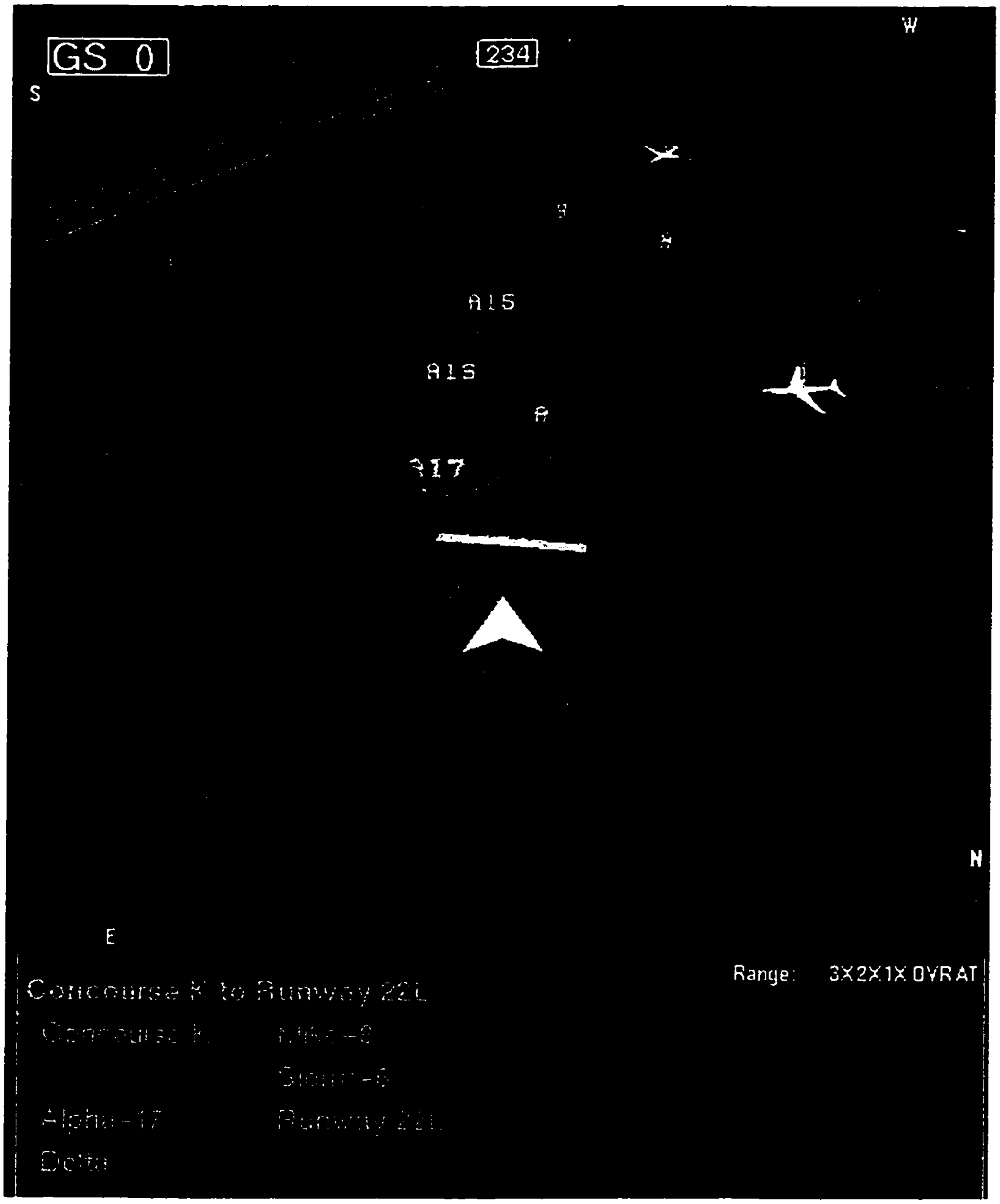

Figure 2: Hold bar.

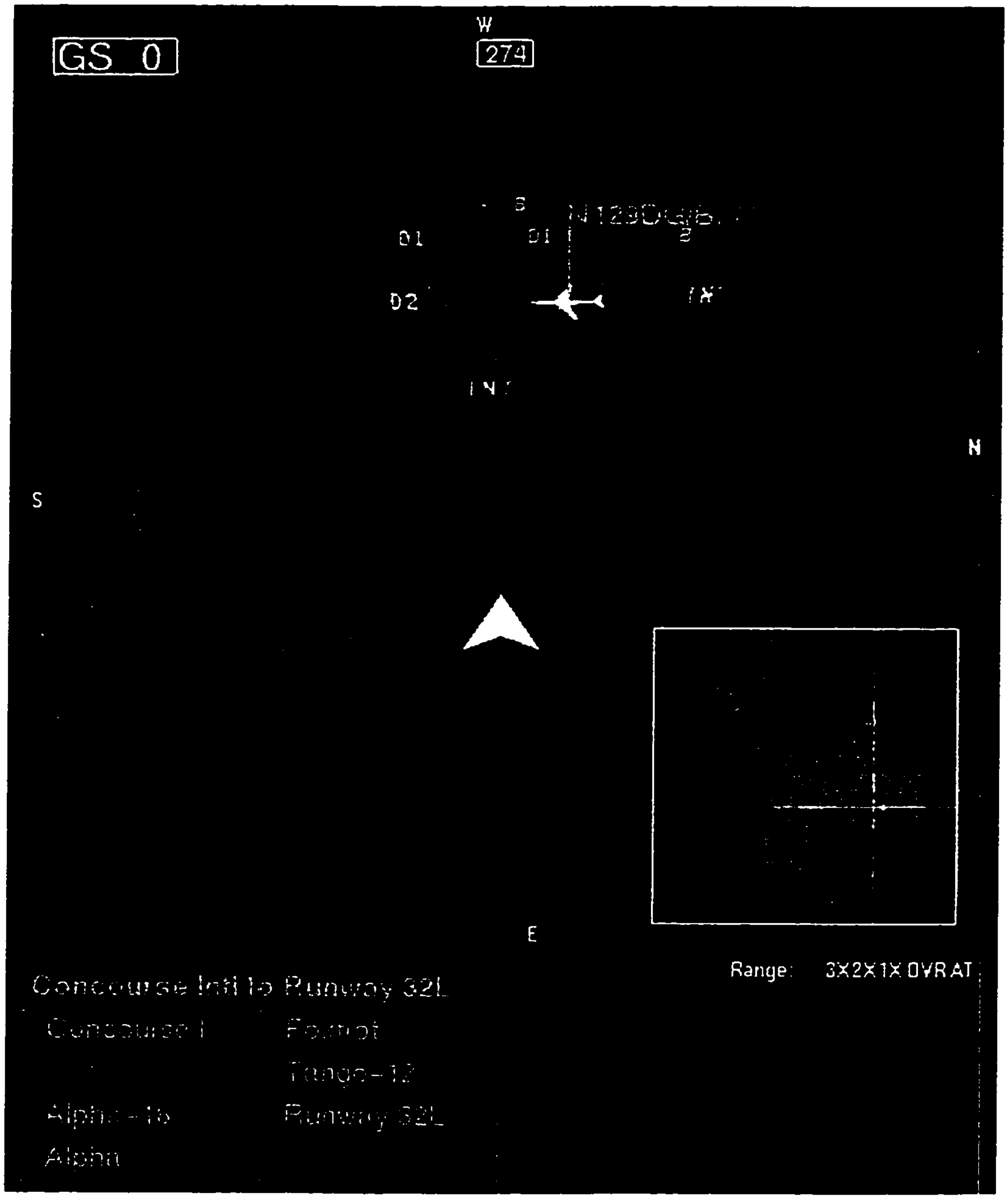

Figure 3: Inset.

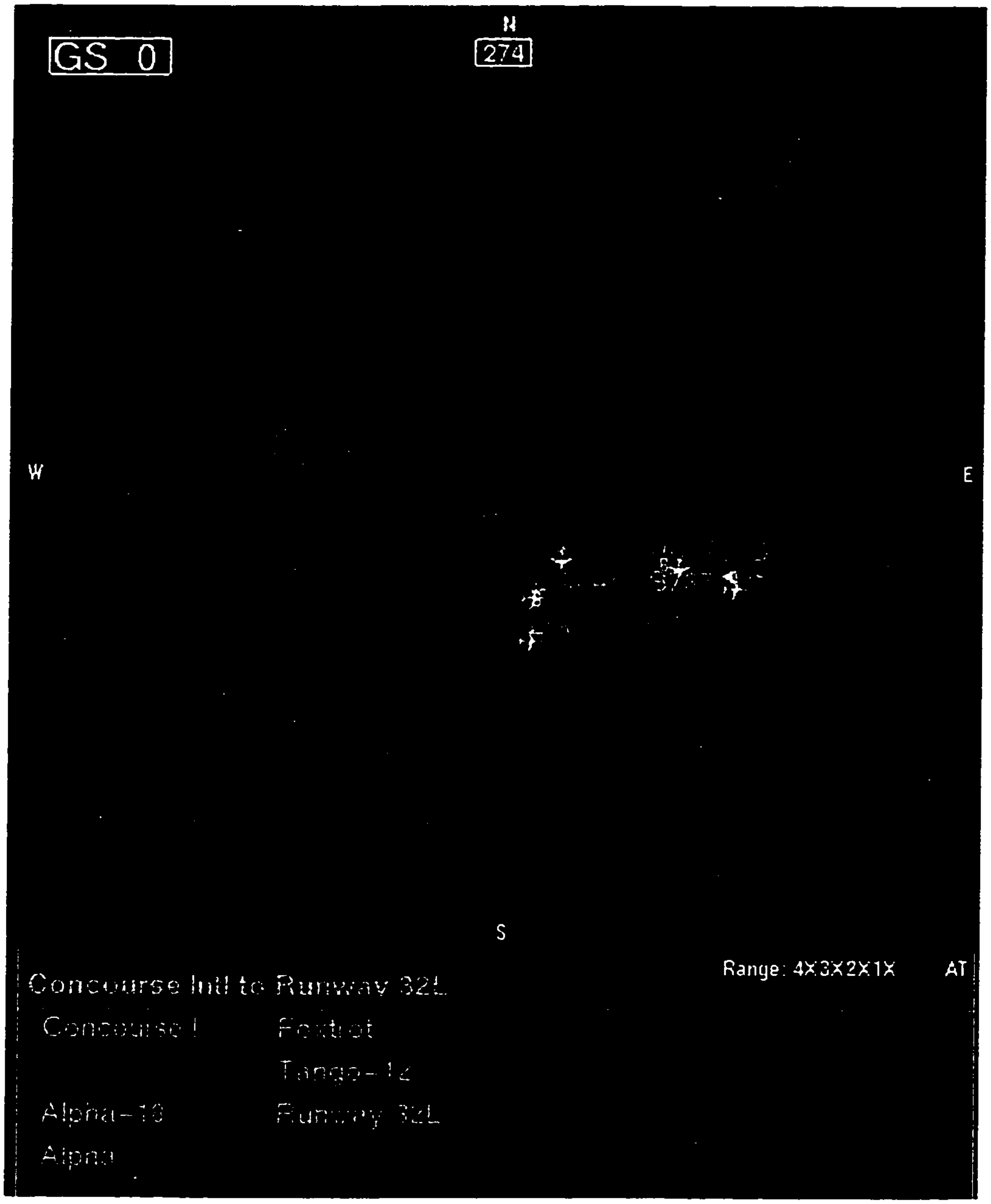

Figure 4: Overview.

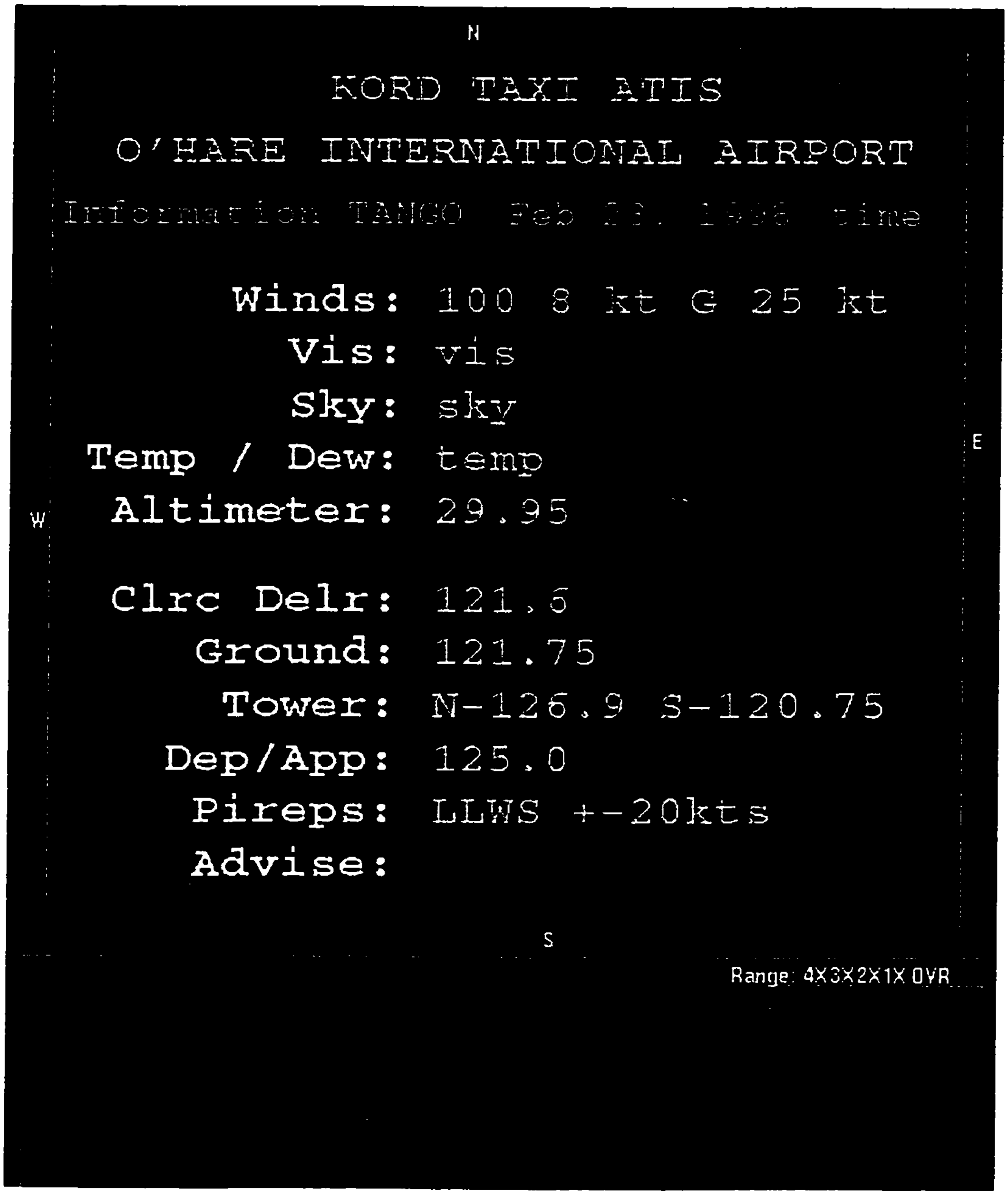

Figure 5: Taxi ATIS

Appendix F. EMM Usage Instructions

EMM Usage Instructions

The Electronic Moving Map (EMM) display has been carefully design to aid eyes-out taxi. There are several features that have been purposefully built into the display to assist you in taxiing while keeping eyes-in time to a minimum. The following is a brief set of instructions that explain how the EMM should be used during taxi.

The EMM is designed to be a secondary navigational aid, **NOT** a primary or centerline tracking display. To keep you from using it as a primary display or tool for tracking the centerline of the taxiway we built in various aspects. First, we used a thick magenta band, the width of the taxiway, to show the cleared route instead of highlighting the taxiway's centerline. Second, the ownship icon is a triangle that is slightly larger than the taxiway so that it can be used to assess your general position on the taxiway (am I on taxiway Alpha?), but not the specific position of the aircraft's wheels. Third, we did not include turn vectors or predictors to aid turning.

The EMM is also designed to allow information to be gleaned from quick glances at the map. The EMM is a rotating map, therefore eliminating the need for mental rotation because what is displayed on the upper portion of the display is always what is in front of you. The wedge also affords this because it helps you find the OS icon, gives you the general heading of your aircraft, and area of importance 1,250' in front of the aircraft. By implementing these features, instead of fine detail control features, the map is designed to aid you in navigating the airport eyes-out instead of tracking the centerline and navigating eyes-in.

We feel that taxiing is an eyes-out process and we incorporated that philosophy into its design, as noted above. The map is there for you to verify heading, position on the airport surface, position relative to the cleared taxi route, the cleared route itself, ground speed, traffic movement and identification, and hold bars. It is not there to aid you in turning the aircraft, tracking the centerline, or to replace the out-the-window view. This display was not designed with the intent of making it a primary navigation aid, instead it should be used as a secondary navigation (rather than control) aid which can be incorporated into your scan pattern. It assists you in eyes-out taxi by providing information that is otherwise lost or degraded due to poor visibility. Please keep this in mind while using the EMM today and let the experimenter know when you are ready to begin.

Appendix G. Survey 1

Survey 1

I. Map Use

1. Please rate how often you used the display while taxiing in each of the visibility conditions

Day VMC

Very often		Neutral		Did not use
1	2	3	4	5

Day 700' RVR

Very often		Neutral		Did not use
1	2	3	4	5

Night 1,400' RVR

Very often		Neutral		Did not use
1	2	3	4	5

2. For Day VMC visibility condition indicate whether or not you used the map to do the following:

- Verify Heading: Yes No
- Verify position on the airport surface: Yes No
- Assist turning the aircraft: Yes No
- Verify position relative to the cleared taxi route: Yes No
- Verify the cleared route itself: Yes No
- Verify ground speed: Yes No
- Track the taxiway centerline: Yes No

- Verify traffic movement and identification: Yes No
- Verify hold bars: Yes No
- Replace the out the window view: Yes No

3. How did you use this display (Please circle one)

- Primary navigation display
- Secondary navigation display
- To control the aircraft

II. Visual Attention

4. For each visibility condition how often did you fixate on the following map features and why:

Day VMC

- *Heading Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ownship Icon*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Digital Compass Heading*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ground Speed Indicator*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Route Guidance*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Traffic Icons*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Hold Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Text Box*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Wedge*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

Day 700' RVR

- *Heading Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ownship Icon*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Digital Compass Heading*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ground Speed Indicator*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Route Guidance*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Traffic Icons*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Hold Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Text Box*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Wedge*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

Night 1,400' RVR

- *Heading Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ownship Icon*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Digital Compass Heading*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Ground Speed Indicator*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Route Guidance*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Traffic Icons*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Hold Bars*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Text Box*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

- *Wedge*

Often		Neutral		Not Very Often
1	2	3	4	5

Why:

5. Were you ever looking at the map when you should have been looking out the window?

Yes No

III. Route Guidance

6. Please rank the three route guidance versions (1 = highest ranking, 3 = lowest ranking)

   - Stays magenta after hold bar___
   - Turns yellow after hold bar___
   - Disappears after hold bar___

7. While holding which of the following did you do (please circle as many as apply):

   - Planed remainder of the route
   - Scanned display for traffic
   - Scanned the out the window environment
   - Kept eyes-in
   - Kept eyes-out
   - Other (please explain):

8. If you circled "Planned remainder of the route" in question 7, please rate your ability to do so for each of the route guidance conditions

   Route guidance stays magenta beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

   Route guidance turns yellow beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

   Route guidance disappears beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

9. Please rate your ability to detect the hold bars for each of the route guidance versions

Route guidance stays magenta beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

Route guidance turns yellow beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

Route guidance disappears beyond the hold bar

Very easy		Neutral		Very hard
1	2	3	4	5

IV. Taxi ATIS

10. How useful would an ATIS be while taxiing?

Very useful		Neutral		Not very useful
1	2	3	4	5

11. Please list any suggested changes:

Appendix H. Survey 2

Survey 2

I. Heading Bars

1) Please rate the usefulness of the heading bars when given clearances for route changes using cardinal directions (i.e. North, South, East, and West). For example, "change route to Whiskey heading South."

Very Useful		Neutral		Not Very Useful
1	2	3	4	5

2) Please circle which item(s) you used for orienting the aircraft in a general heading

- Heading Bars
- Digital Compass Heading
- Both

3) Please rate the Heading Bars on the following dimensions

<u>Use</u>

Very Useful		Neutral		Not Very Useful
1	2	3	4	5

<u>Color Coding</u>

Liked Very Much		Neutral		Disliked Very Much
1	2	3	4	5

<u>Size</u>

Liked Very Much		Neutral		Disliked Very Much
1	2	3	4	5

4) Any suggested changes to the heading bars

II. Clearance Text

5) How often did you read the clearance text

Very often		Neutral		Never
1	2	3	4	5

5a) If you did not circle 5, please write down when you read the clearance text and why

6) Please rate the idea of making the text box selectable. In other words you would have the option to deactivate it and display more of the map.

Great		Neutral		Bad
1	2	3	4	5

7) Please rate the usefulness of the following text box features

<u>Magenta Text Highlights</u>

Great		Neutral		Bad
1	2	3	4	5

<u>Symbols < ></u>

Great		Neutral		Bad
1	2	3	4	5

Appendix I. Interview Questions

Interview Questions

1. Explain your strategy for using the display in each of the visibility conditions.
2. How do you think the display would alter your scan pattern in each visibility condition?
3. What role did the display play in taxiing in each of the visibility conditions?
4. What role did the display play in resolving incursion incidents?