THE INFLUENCE OF ALERTS (CALLOUTS) ON PILOT VISUAL ATTENTION TO AN ELECTRONIC TAXI MAP

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ABSTRACT

THE INFLUENCE OF CALLOUTS ON PILOT VISUAL ATTENTION TO AN ELECTRONIC TAXI MAP

by Kevin Patrick Purcell

NASA's Taxiway Navigation and Situational Awareness (T-NASA) in-cockpit Electronic Moving Map (EMM) has been found to improve the efficiency and safety of airport surface operations. Its design also leads to a paradox: the EMM requires the pilot to look head-down into the cockpit, diverting attention away from the primary, out-the-window (OTW) view. The present study examined the potential benefits of pilots attending to the EMM only when directed by either audio or visual "head-up" callouts. The callouts were presented in either a general ("check map") or specific ("turn right onto Bravo") form. The visual attention effects of these callouts were assessed using an eye tracking system during a medium fidelity, part-task ground taxi simulation. Performance and behavioral eye-tracking data revealed that the presence of callouts, especially audio specific, reduced the visual attention demand of the EMM, while maintaining the same level of taxi efficiency and improved levels of navigation accuracy and incursion detection performance relative to the no-callout condition.

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INTRODUCTION

Air Capacity Problem

In the past decade, the National Airspace System (NAS) and major U.S. airports have become burdened with delays and over crowding. 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). To counteract these delays with their accompanying economic losses, the root causes must be addressed, with particular emphasis on poor weather.

TAP Program

Pilots currently taxi to and from the terminal using paper maps (Jeppesen charts), OTW visual cues, and directions from air traffic control (ATC). To address these issues, NASA s Terminal Area Productivity (TAP) program was created in an effort to safely increase airport throughput in low visibility conditions, by using recent technological advances.

T-NASA

One component of the TAP program to aid the taxi task is a flight-deck display suite designed at NASA Ames Research Center called the T-NASA (Taxi Navigation and Situation Awareness) system. T-NASA uses three components to counteract the problems created by taxiing in low visibility: A head-up display (HUD) unit, a 3-D audio ground collision avoidance warning system (3-D GCAW), and an electronic moving map (EMM).

Part-task simulations conducted at NASA Ames have shown that the T-NASA system is able to significantly increase forward taxi speed, decrease route-planning time, and decrease navigation errors. For example, a recent part-task simulation found that with the T-NASA system, pilots experienced an average increase in forward taxi speed of 1.5kts and a virtual elimination of navigation errors (McCann, Andre, Begault, Foyle, & Wenzel, 1997). It has been projected that the potential savings of implementing the T-NASA system at LaGuardia, Newark, or JFK airport would be $1-3 million per year per airport, not to mention added safety benefits (D. C. Foyle, personal communication, August 2, 1997).

The Taxi Task

According to Lasswell and Wickens (1995) the aircraft taxi task falls into two subtasks, local guidance (which includes information gathering from both inside and outside the aircraft) and global awareness (which includes information almost exclusively gathered outside the aircraft). Both of these subtasks require a division of attention between the head-up OTW and the head-down instrument display domains during ground taxi operations. It is therefore important to integrate related information acquired from both domains in order to reduce cognitive processing demands upon the user. Accordingly, it is critical that the information presented on the EMM supports the optimal allocation of visual, attentional, and cognitive resources.

Electronic Moving Map (EMM)

Design philosophy. Based on field research conducted by Andre (1995), the T-NASA team developed the EMM with the philosophy of supporting eyes-out taxiing (Foyle, Andre, McCann, Wenzel, Begault & Battiste, 1996). The EMM provides a 3-D perspective view of the airport surface from a vantage point above and behind the ownship position, furnishing graphical route guidance in the form of a magenta-colored line or ribbon extending along the cleared taxiway path (McCann, Foyle, Hooey, Andre, Parke, & Kanki, 1998). This perspective view was chosen over an overhead 2-D plan view in that the 3-D display creates a visual momentum between the OTW view, the EMM, and other T-NASA displays (Tu & Andre, 1996).

The EMM was also designed to be a secondary navigation display that aids situational awareness (SA), navigation, orientation, and planning. The EMM was not designed for local guidance/controlling the aircraft, such as steering or tracking the centerline, rather it was designed to support allocation of resources for global awareness. Since this display was not designed for a no-visibility condition but rather a low-visibility condition, it was deemed unnecessary 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.

Performance issues. Previous studies have shown EMMs to increase both performance and safety (e.g., McCann et al, 1977). In a simulation looking specifically at the differences between electronic and paper maps in navigating the airport surface, Batson, Harris, and Hunt (1994) found the average taxi speed increased as much as 24% under both good and poor visibility with the use of electronic moving maps. They also found that pilots made only one third as many navigation errors and had better awareness during taxi when using an EMM. Irwin and Walter (1996) looking at a 1996 EMM study by Battiste, Downs, and McCann (1996) also examined crew navigation strategies in regards to when errors were committed. They found that in 9 of 19 cases where errors were committed, crews using the EMM were able to correct their errors without contacting ATC. Their mean correction time was 93 seconds for the paper map condition but only 31 seconds for the EMM condition. Previous T-NASA simulation studies pitting EMMs vs. paper maps, have shown that the EMM alone, partialed out from the T-NASA system, produces significant differences in taxi performance. In a part-task simulator study of the T-NASA components (McCann, Foyle, Andre, & Battiste, 1996, McCann et al., 1997) 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. From these and other studies, it is apparent that EMMs 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.

Behavioral issues. While performance enhancements brought by the EMM are well documented, the behavioral issues of how pilots interact with the EMM are still largely in question. The work by Battiste et al. (1996) also 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. Through videotape evidence, Captains head-up time was discovered to be significantly reduced with the introduction of an EMM, averaging 84% head-up time with the paper map, while only 65% head-up time with an

EMM. During development of the T-NASA EMM, a major concern was its potential for pilots to use the display for aircraft control, staying head-down eyes-in, and to rely too heavily on the automated map in decreased visibility.

The first T-NASA study specifically examining pilot visual attention to the EMM was conducted by Graeber and Andre (1999) looking at the effect of instructing pilots on use of the T-NASA EMM. They sought to increase visual OTW attention and decrease head-down time attending to the EMM by the introduction of usage instructions. These usage instructions informed the pilots that the display as designed was to be used as a secondary navigation aid to eyes-out taxi, not a primary centerline tracking display. The data gathered showed that pilots use their scanning strategies to view the EMM efficiently whether given usage instructions or not, and under both high- and low-visibility conditions. Still, providing instructions on EMM usage did significantly alter user behavior, showing 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).

Utility-Visibility Paradox

The design of most automated information systems brings with them at least one paradox. Current studies suggest that increasing automation on the flight deck is occasionally increasing pilot workload (Damos, John, & Lyall, 1999). During studies of driving navigation systems Dingus, Hulse, and Barfield (1998) found what Dingus and Hulse (1993) earlier called an out-of —the-loop loss of familiarity problem.

> Presently, the driver is required to obtain most information from the outside driving environment. As more information is presented in the car the driver is less likely to obtain the same information from the driving environment . Thus, there is a trade-off: the more powerful and informative the system, the more the driver will rely on it to provide information rather than search the driving environment for it (p. 382).

Of course, in many ways, driving a car and taxiing an aircraft are similar tasks. Indications that performance suffers when drivers are looking at various in-vehicle displays rather than OTW are many. For instance, driving studies show that when attending to head-down displays drivers do not react as well to situations on the road, deviate more from their course, and do not reduce their speed when necessary (McKnight & McKnight; Zwahlen & DeBald; Walker, Allicandri, Sedney, & Roberts; all as cited in Dingus, Hulse, et al. 1998). In a study looking at in-vehicle automobile navigation Advanced Traveler Information Systems (ATIS) Lee, Gore and Campbell (1999) found that drivers often distribute their attention inappropriately, suggesting that the evaluation of in-vehicle information systems should consider the inappropriate distribution of attention.

The performance gains provided by the power of the EMM suffer from a similar paradox. The EMM can lead to superior taxi performance, but its design also encourages a head-down eyes-in behavior at a time when it is crucial for the pilot to be looking OTW. While Graeber and Andre (1999) and Lasswell and Wickens (1995) found this eyes-in cost was operationally insignificant, their experimental simulations might not have yielded the appropriate context in which a high allocation of attention to head-down displays (e.g., the EMM) produces a cost to efficiency or safety.

The present study examines ways to further increase efficient use of the EMM in low-visibility conditions. To explore the issue of how to maximize the utility of the EMM while minimizing its visual demands we must first establish the very factors comprising visual attention demand.

Attentive Demand Mechanisms

Moray (as cited in Hooey, 1995) theorized a mental model by which people allocate and control attentional resources. Mental models are developed by the subject according to statistically expected properties of events in the operator s environment, which in turn are used to guide their visual sampling. If an operator receives more information from the display than the environment, he/she will expect it and sample the display more frequently (Dingus, Hulse, et al., 1998), which leads us into the utility-visibility paradox.

Attention can be controlled by two theoretical mechanisms: internal and external (see Figure 1). Internal mechanisms are a self-based, top-down attentive process where the user s goal and event expectancies drive their allocation of attentional resources (Hillstrom & Yantis, as cited in Hooey, 1995). External mechanisms are a bottom-up, event-based attentive process where a salient stimuli in the user s environment drives what is selected for the allocation of attentional resources. However when externally stimulus-driven and internally goal-driven approaches vie against one another such that a visually salient stimulus occurs in addition to goal-directed instructions, Bacon and Egeth (as cited in Hooey, 1995) argue that the goal-directed allocation of attention overrides stimulus-driven attention capture. Further work by Folk, Remington, and Wright (1994) similarly argue that attentional capture is not purely a function of the presence of an external stimulus property (what they call abrupt onset), but depends on the existence of a prior internal attentional set . Their proposal, called the contingent involuntary orienting hypothesis, argues that attention capture is contingent on top-down, subject-defined attentional control settings induced by task demands. These attentional control settings however are broadly tuned, distinguishing only between stimuli of either static or dynamic discontinuities. A lack of selectivity in attentional capture was found between different these forms and clearly requires further study.

Currently the attentional process of taxiing with an EMM is more internally goal-driven, with user-defined scanning and repeated, frequent glances. The goal of the present study is to base the pilots use of the EMM on a more external, event-driven process whereby the pilots need to view and respond to events displayed by the EMM are prompted by some external cue or callout (see Figure 1). Toward this end goal, we next discuss the different human sensory modalities and their possible use as attention callout mechanisms.

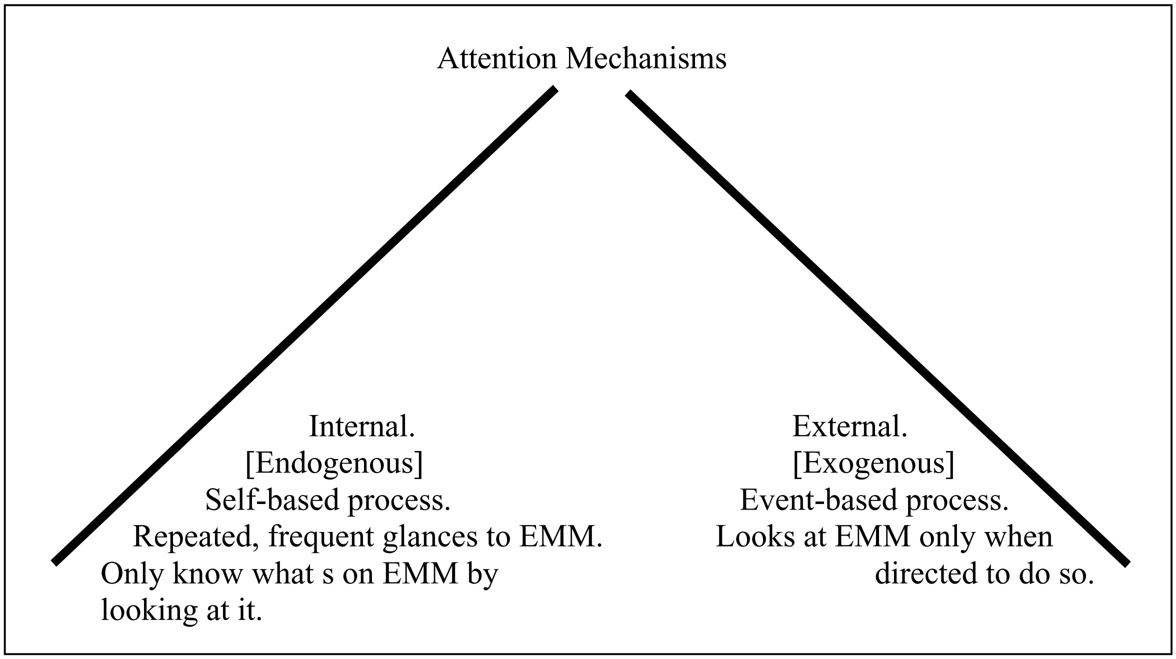


Figure 1. Self-based internal vs. external attention mechanisms.

The tactile modality. Although rarely used as the primary display for the transference of information, the tactile modality has been successfully used to transmit redundant information (Sklar & Sarter, 1999). The most common example of this is the raised surface on the F and J keys on a keyboard to indicate the position of the index fingers for the home row. In addition to transmitting redundant information, feedback can also be transmitted. Driving study experiments have been carried out on gas pedal designs that provide force feedback - when the sensored automobile detects it is following a car too closely the force needed to maintain the current accelerator position increases (Dingus, Hulse, et al. 1998). This study found the design successful at increasing following distances. Other driving studies have found anecdotal evidence that drivers accept tactile information more readily than auditory. Drivers may become embarrassed by the activation of an auditory warning or alert when there are passengers in the car.

In the aviation field there is the stick shaker tactile display on aircraft that are in danger of stalling; the control column will vibrate alerting the pilot to take corrective action (Dingus, Hulse, et al. 1998). More recently the U.S. Navy has been developing the Tactile Situation Awareness System (TSAS), consisting of a vest with rows of dime-sized tactile sensors built into it (Wilson, 2000). As an aircraft changes attitude, sensors in the vest vibrate the pilot s chest, back, or sides, giving them a piece of information about the position change. The information imparted is intuitive; freeing up cognitive and visual resources that might otherwise have been used.

While the tactile modality is a promising channel as an alerting mechanism, it was not examined in this study.

The visual modality. When driving 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 (Graeber & Andre, 1999). One approach to deliver increasingly available information to the pilot using the visual modality has been the Head-Up Display. In order for the pilot to attend to two separate display domains of head-up OTW and head-down instrumentation, visual scanning between the two is necessary. Saccadic eye movements serve this scanning, but because of the lack of time required to shift fixation, performance was constrained. Head-up displays (HUDs) spatially organize information from these two viewing two domains, superimposing the head-down instrument display over the head-up scene via a transparent screen. This results in a single display where one information source is in very close proximity to the other, integrating two information pieces into a single perceptual unit. This display makes large eye-scan movements unnecessary and theoretically facilitates parallel processing of both information sources.

Studies of drivers using HUDs theorized a benefits time window (Kiefer, 1996), where the biggest advantage of a HUD is the time period when the driver s eyes are in closer proximity to forward events, facilitating parallel processing and virtually eliminating visual scanning. The present study employed a head-level visual display as one method of presenting alerts (callouts) concerning critical navigation events.

The auditory modality. The visual modality or channel has been increasingly overused as a method of information deliverance to the pilot. As the visual channel has become overloaded, the audio channel has been recognized as a possible method for operator information delivery (Perrott, Cisneros, McKinley, & D Angelo, 1996). The auditory modality has the unique feature of being able to transmit information without requiring the operator to divert his/her vision from another task (Wickens, 1992).

According to multiple resource theory, when two concurrent tasks share working memory resources it is more likely that task interference and difficulty-performance trade-offs will occur (Wickens, 1992). This suggests that in many contexts, operators can better time share a visual (navigating an aircraft on the ground) task with an auditory task (an auditory event cue) than two visual (or auditory) tasks. Indeed, studies have shown that a discrete route guidance task is better presented aurally than visually while subjects are concurrently driving a simulated vehicle. According to Wickens (1992) these findings occurred because cross-modality time-sharing was better than intramodal time-sharing. Thus, the auditory channel appears to be a promising method for delivering attention cues. (Note that cross-modality benefits are not always observed. For example, Wickens and Liu, (1988) found when visual scanning is carefully controlled, time-sharing from cross-modal displays do not invariably bring better performance.) The present study employed an auditory display as one method of presenting alerts (callouts) concerning critical navigation events.

Callouts

A potential method for avoiding the utility-visibility paradox is the use of attention cueing, or callouts. It has been shown that prior knowledge of a target position (cueing) facilitated performance for a briefly presented target (Posner, as cited in Hooey, 1995). Despite eyes remaining focused on a central fixation point, studies have shown that reaction times were faster to respond to the presence of a target because attention was shifted towards the cued area. This is the reasoning behind the use of a callout. A callout is defined as an attentional or informational cue designed to provide the pilot with a cueing mechanism for attention to be directed to, in this case, the head-down EMM. The goal of the callout is to change attention to the EMM from an internal, self-based, goal-driven process to one of an external, event-based, stimulus-driven process. A secondary goal of the callout is to eliminate the operator s reliance on using potentially erroneous user-defined expectancies to drive their visual scanning processes.

Previous callout research. Previous research into utilizing the audio channel for adding information to navigation and other automatic operations has produced positive performance results. Labiale (as cited in Dingus, Hulse, et al. 1998) showed that when navigation information is presented aurally rather than visually the operator workload during guided-route following is lower. Information-processing resources can be allocated across modalities efficiently because an additional channel for processing information is being used. Studies have indicated that systems using a voice audio display can improve the allocation of attention among tasks, improve information integrated into operator decisions, and do not necessarily add to the operator s attentional load (Dingus, Jahns, et al. 1998). A study by Perott, Saberi, Brown and Strybel (as cited in Begault, 1993) found the presence of information from an auditory source substantially reduced the time to acquire and identify a visual target.

Not all callouts are the same however, as audio and visual cognitive processing requirements often differ. A recent study found that drivers looking at visual messages did not input accelerator commands while messages were being processed (Kantowitz, Hooey, & Simsek, 1998). This is consistent with the idea that auditory input requires less attentional capacity than visual input because of higher compatibility between stimulus and response. According to Green, Levison, Paelke, and Serafin (1993), a verbal format is superior when a complex message is presented via the auditory channel because they are more flexible and informative than sounds and are more effective during high workload situations.

The omnidirectional nature of auditory displays makes them very desirable for alert and warning messages (Wickens 1992). According to Begault (1993), audio is essentially a head-up display and like visual HUDs, so too are there aural callouts already on the flight deck. A number of attentional tones and verbal commands are already given to the flight crew by TCAS, navigation systems and various other avionics systems currently in use.

Auditory callout costs. Though performance of task is sometimes enhanced through use of the audio channel, behavioral questions remain. In a 1998 study of pilots confronted with the future deployment of the T-NASA system pilots stated that they still want to check in with a real human voice controller: A controller is needed as an active participant in this system . I d be nervous just following the [ATC directed] magenta line with no voice control (Hooey, Schwirzke, McCauley, Purcell, & Andre, 1998, p. 30).

Some potentially negative aspects however of using speech presentation have been cited by Dingus and Hulse (1993), including an instinctive reaction to voice commands even when they conflict with other information. Kantowitz, Hooey, and Simsek (1998) point out that designers of navigation systems should be aware that specific auditory messages can be understood as commands or orders, and carry an attendant risk for these user instinctive reactions.

Callout design guidelines. Undisciplined design of audio and visual presentations of information has been found to distract rather than inform. Dingus, Jahns, et al. (1998) state that If an alarm imposes a high demand on driver attention or annoys the driver to the point where avoidance performance is unchanged or decreases, then the alarm may not even be useful (p. 74). Visual display problems such as scanning versus perceptual competition or display clutter, and guidelines for working with these problems, are well documented in the literature (Wickens, 1992). Several display guidelines have been developed using multiple resource theory, attention theory and field study findings.

For multiple visual displays it has been recommended to prioritize displays by location (Dingus, Hulse, et al., 1998). One display in the center of the visual scene for foveal vision and emergency warnings minimizes visual demands. The other display(s) should be off the center of the visual scene, for advisory warnings. The location of the display for the operator would become associated with the urgency of information.

For audio displays, it has been recommended that since pilots prefer visual to auditory warnings when there is time to react, auditory sounds for non-urgent warnings should be avoided. An alternative approach currently in use in cockpits is to use pleasant sounds or tones for lower-priority auditory advisories (Dingus, Jahns, et al. 1998). Green, Levison, et al. (1993) also recommend using non-speech messages only for the purpose of lower-priority alerting, either as a self-contained message or as a method of alerting or calling out to the driver to an in-vehicle visual message or to a spoken message that follows.

Since speech is more effective during higher operator workload, Dingus and Hulse (1993) recommend that the auditory modality be used as a prompt for a visual display of changing or upcoming information. This would reduce the need for the driver to constantly scan the visual display in preparing for an upcoming event (Dingus, Jahns, et al. 1998). An auditory display could also be paired with a simple visual display that supplements the auditory message, so that an auditory message that is not fully understood or remembered can be checked or referred to later via the visual display. To design the auditory information in a way that it will enhance the visual information, a study by Robinson and Eberts (as cited in Dingus, Hulse, et al. 1998) maintained that the optimal display design would combine desirable features from speech displays (e.g., warning or alerting capability) with the spatial orientation provided by visual displays. Finally, voice messages due to their higher information content can also indicate whether new information is available so that the driver need not glance at the visual display frequently to check for updates.

Callout specificity. In addition to the modality of the callout to be used, another issue to address is the specificity, or informativeness, of the callout. There are two levels of callout specificity that can be implemented. A general callout simply signals to the pilot that some event or condition exists that warrants his or her attention to the EMM. This is likened to a general caution indicator in an automobile or aircraft. A specific callout provides information as to the specific nature of the event or condition (e.g., You are off route). The present study seeks to examine the effect of callout specificity on attention to the EMM. We hypothesize that the specific callouts will allow pilots to focus more attention OTW and to respond more efficiently to callout events.

Summary

While taxi performance in a low-visibility, high attentive demand environment has already been found to benefit from the use of an electronic map display, the EMM design brings with it a paradox: the EMM affords a head down, eyes-in position of gathering information from the map at a time when it is important for pilots to be head up, scanning the OTW display. However, if pilots do remain head-up looking OTW they gain little new information due to the low visibility, and lose the power of the updated information about their situation brought by the EMM.

There are potential tradeoffs to utilizing either voice or visual callouts in an effort to externally guide pilot s visual attention to the EMM. Callouts given by voice have the potential to increase the head-up time looking at the OTW display while decreasing time spent head-down looking at the EMM. Multiple resource theory (Wickens, 1992) suggests that modality separation of concurrent tasks, such as navigating while taxiing, will usually make time-sharing in working memory more efficient and changes in difficulty in one task will be less likely to influence the other. There are current guidelines and existing examples of cross-modality time-sharing of attentive resources already in aircraft, such as TCAS, navigation, and various other avionics systems currently in use.

On the other hand, there are potential benefits for using a consistent, visual modality, in an effort to smooth the transition from the callout display to the EMM or OTW.

Clearly, then there are potential benefits and costs of using either the visual or auditory modality for the presentation of EMM callouts.

The Present Study

The objective of the present study was to compare auditory vs. visual callouts, across both general and specific levels of informativeness. We collected objective data on taxi performance, eye tracking data the to see how visual attention and scanning behavior changed, and subjective data on callout mode preference. From this information we will hopefully be able to tease out the role callout modes and specificity play in the distribution of pilots visual attention between the OTW scene and the EMM, and the subsequent effects on taxi efficiency and safety.

We hypothesized that when taxiing, pilots are trying to attend to dynamic visual stimuli. Adding either a visual or auditory cue for keeping eyes OTW while aiding situational awareness would decrease eye dwell time and the percentage of eye dwells on the EMM, as well as increase the taxi and safety performance measured. A visual callout would aid in low visibility navigation, but an audio callout given by voice, by adding information so that the user can better utilize the over-abundance of visual information presented, would lead to even better performance and scanning behavior. Still, the auditory callout display might be found annoying by some users.

METHOD

Design

Two factors were manipulated in a within-subjects design. Callout Mode was varied over two levels: visual and auditory. Callout Specificity was varied over two levels: general and specific. The current method of using the EMM with no callout mode given by the system was included as a control condition.

These factors combine to create five experimental conditions: 1) control condition with no callouts, 2) visual general callout, 3) visual specific callout, 4) auditory general callout, and 5) auditory specific callout.

There was one practice trial at the beginning of the experiment and five trials per condition, resulting in 26 total trials. All trials were counterbalanced. Taxiing visibility was set at 700 daytime RVR. There were 127 total general callouts and 179 total specific callouts over the 25 trials.

Callout modes. We compared two different callout modes: visual and auditory. To support processing of the visual callout while maintaining a head-up, eyes-out posture, the visual callout was presented on a head-level visual display (see Figure 2) akin to the location of the mode control panel on most commercial aircraft. Our goal was to support the potential for the pilot to attend to the visual callout while looking out the window, and without the need to make a head movement from the OTW view. The visual callout consisted of text printed on the VC display screen in this head-level position (see Figure 2).

The audio callouts consisted of voice announcements that would sound at the same moment as the text display but audibly speak the words instead of textualizing them. As audio is a head-up display (Begault, 1993) again the operator would be able to stay focused OTW.

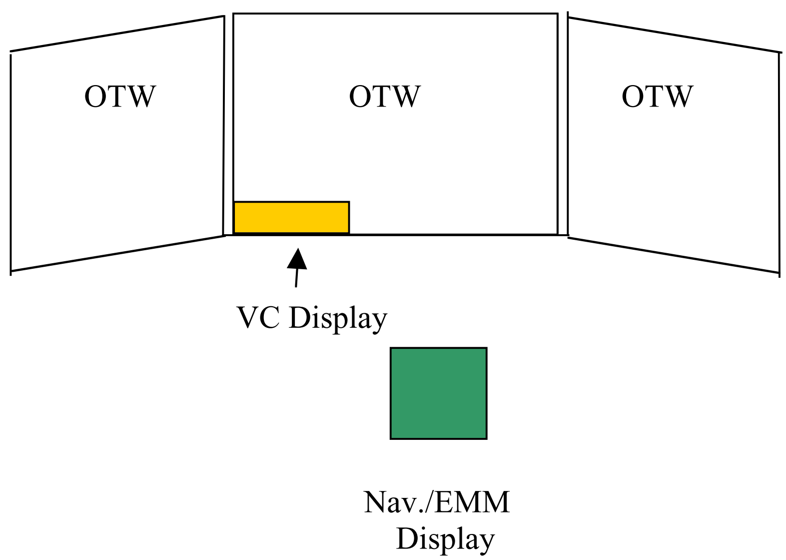


Figure 2. Layout of visual callout display.

Callout events — turns and holds A list of callout events and callout language is shown in Table 1. For visual callouts, the text message that appeared on the VC for general callouts regarding upcoming turns consisted of the two words Check Map . For upcoming holds and their accompanying proceed from holding messages the text consisted of Hold Short and Proceed Across .

The text messages that appeared on the VC for specific callouts consisted of the following: Turn Left/Right onto next intersection/runway (e.g., Turn Left onto Bravo 3), Hold Short of next intersection/runway (e.g., Hold Short of Bravo 3), and Proceed Across next intersection/runway (e.g., Proceed Across Bravo 3).

For audio voice callouts, messages that were spoken in the cockpit by the T-NASA system for general callouts consisted of the same words that made up the visual callouts: Check Map for upcoming turns, Hold Short and Proceed Across for upcoming holds and their accompanying proceed messages. The audio messages that were spoken for the specific callouts also consisted of the same words as the visual specific callouts: Turn Left/Right onto next intersection/runway (e.g. Turn Left onto Bravo 3), Hold Short of next intersection/runway (e.g. Hold Short of Bravo 3), and Proceed Across next intersection/runway (e.g. Proceed Across Bravo 3).

Regardless of the callout condition being tested, there was an audio callout anytime a subject taxied off the prescribed taxi route that said Off Route .

All upcoming turn messages were given an advanced notice similar to the prepare warning suggested by Green, Levison, et al. (1993). The distance to the turn that the subject received this warning was either 600, 300 or 100 feet depending upon if the turn was preceded by a long straightaway of another turn. Depending on the pilot s taxi speed this gave an advanced warning time ahead of the turn approximately 5 to 10 seconds. All hold shorts were graphically represented on the taxi route. All hold callout messages were given at a distance of at least 600 feet.

Table 1

Callout Events and Text/Audio for General and Specific Conditions

Event Type	**General Callout**	**Specific Callout**
Turn Ahead	Check Map	Turn Left onto Bravo 3
Hold Short	Check Map	Hold Short of Bravo 3
Proceed Across	Check Map	Proceed Across Bravo 3
Traffic Advisory	Traffic Advisory	Traffic Advisory, Traffic on Left/Right
Collision Warning	Collision Warning	Collision Warning, Traffic On Left/Right

Callout events — preplanned incursions To evaluate safety aspects and the effectiveness of the EMM display with and without callouts, potential runway incursions were investigated. Incursion trials were those 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. For those trials that another aircraft came within a distance of 1250 ft., the airplane s icon on the EMM would turn from white in color to yellow. If the subject was under one of the callout conditions a Traffic Advisory callout was also given for general callouts, Traffic Advisory, Traffic on Left/Right was given for status callouts. If the traffic aircraft remained on an intercept course with the OS after this yellow/traffic alert and came within a 5 second time to impact or a 300 ft. distance, the traffic s icon would flash red and the general callout COLLISION WARNING would be given if the trials were of the general callout type. If the trials were of the specific callout type, COLLISION WARNING, TRAFFIC ON LEFT/RIGHT would be given. The incursion callout mode presented would match the mode that the turn/hold mode presented.

Impact from the incurring aircraft would only be avoided by correctly responding to the warning logic on the EMM (traffic symbol turns red and begins to flash) or holding short when instructed to do so. Located on the subject s left was the joystick/tiller, which steered the front nose wheel. There were also two buttons located on top of the tiller, right and left. The correct response to the warning callouts was to press the corresponding button that the traffic incursion was coming from during the 5-second collision warning callout. The incurring aircraft will be given a hold bar and stopped, and the subject would be given a message to proceed. If the subject did not press the proper button in the allotted time, the OS was given a hold bar and the incurring aircraft was allowed to proceed.

Participants

A total of 15 commercial line pilots, five captains and ten first officers with taxiing experience, participated in the study. To facilitate the use of the eye tracker only participants with uncorrected vision or soft contact lenses and no color vision deficiencies were used.

Apparatus

Simulation hardware. The hardware used for the experiment consisted of several components. The simulated environment was created using a Silicon Graphics Onyx 10000 Infinite Reality workstation projected onto a 6 high by 8 wide screen 8 from the participant s eye point using an Electrohome rear-projection unit. Two side windows were also present and were displayed on two 19 Silicon Graphics monitors three feet from the participant s eye point. A Silicon Graphics Reality Engine 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 feet from the participant s eye point.

A Silicon Graphics 320 was used to create the visual callouts on the VC. The VC display that appeared above the EMM was placed behind and slightly above the EMM, and was displayed on the top half of a 15 NEC Multisync 4FGe monitor (see Figure 2). Audio callouts were a recorded female voice driven by the computer running the OTW scene and were produced by a Roland S-760 16 — bit sampler.

The participant was seated in an adjustable seat from a Chrysler Laser that was mounted on a motorized sliding track. This seat gave the pilot approximately a 42 inches distance from the EMM, 45 inches from the EMM to their eye point (D). The EMM is approximately 8 inches high (H) by 6 inches wide (W), which subtended a visual angle of ~10.2 degrees. The text for the visual callouts was approximately 0.62 inches high which subtended a visual angle of ~ 0.85 degrees.

In order to control the simulated aircraft, a Boeing 737, the participant was provided a throttle, a nose-wheel tiller with left and right incursion response buttons, and rudder pedals with toe brakes.

Experimenter station. 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. Pilots were given a headset, with hot mike , to communicate with the experimenter/ATC.

Eye-tracker system. To categorize and objectively measure participant s visual attention to the callout modes we used an eye tracking approach similar to the one used by Graeber and Andre (1999). 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.

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.

Taxi routes. Each subject taxied through 25 experimental route/trials around Chicago O Hare airport. Each experimental condition made up a group consisting of 5 different route/trials. Each group had routes containing 25 or 26 turns, 2 Hold/Proceed commands, 1 alert incursion, and 1 warning incursion. This was done in order to counter-balance the numbers of turns, callouts, holds and incursions across each group. The presented order of the routes, callouts, holds and incursions in each group was partially randomized.

Procedure

Participants were met in a room separate from the part-task simulator. At this time, they were given a low-risk consent form to sign (see Appendix A) and a demographics form (see Appendix B) to fill out. All participants were then given a set of general instructions explaining the general experiment (see Appendix C) and a set of instructions explaining the map features (see Appendix D). The participants were then given EMM usage instructions to read at this time (see Appendix E). These usage instructions were the same ones Graeber and Andre used in their 1999 behavioral study, which became the baseline condition this for study. It explained that the EMM was to be used as a secondary navigation aid, not a primary display, and 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.

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, and toe brakes worked. After answering any questions regarding the aircraft control devices, the participant was given a chance to practice taxiing on an extended route around O Hare airport. The practice trial included traffic that was represented on the map and in the OTW scene. 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. In this practice trial, one of the traffic aircraft was designated an incursion. When the pilot neared the pre-determined incursion point, he/she was instructed to slow the aircraft to approximately five knots while the experimenter explained how the EMM would represent the incurring aircraft. For trials in which incursions took place the pilot was given a window of time, a maximum of five 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 Proceed Across command was given and the yellow hold bar was placed in front of the incurring piece of traffic s icon on the EMM. 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) calibration dots were positioned on the instrument panel in front of the pilot. These numbers were in three rows of three; the top row was numbered 1-3, the middle row 4-6, and the bottom 7-9. These dots were spaced 1 apart horizontally and 8.5 vertically. The subject 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, and the reflective glass plate and pupil/corneal reflection laser were then adjusted. A clear image of both the cornea and pupil would appear on the ASL eye tracking monitor. The participant was then asked to hold his 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 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.

Once the eye tracker was calibrated, subjects were given written final instructions on the particular callout mode/specificity condition they would next be tested on (see Appendix F - I). At this point, the part-task simulation was started and participants proceeded through the next five trials of that condition. At the beginning of each trial, ATC (the experimenter) read the clearance text to the pilot and the pilot confirmed by reading back 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 between four to six minutes. After a block of 5 trials, the subjects were given a survey asking about the callout condition they just experienced (see Appendix J). After completing the final trials the subjects removed the helmet, were given the final survey (see Appendix K), interviewed, debriefed, and thanked for their participation.

Dependant Measures

Performance measures were percent time on route, average moving speed, number of navigation errors, and incursion detection. Eye tracking behavioral data consisted of the percentage of trial time fixated on the EMM/OTW/VC displays, number of dwells on the EMM/OTW/VC displays, and the average dwell time on the EMM/OTW/VC displays. Also recorded were the percentage of the trial each zoom level was used on the EMM.

In addition to the above objective data, we also collected subjective data via surveys. The surveys focused on a preference for one callout mode over the other, or preference for a combination of the two. Questions on strategies for their use were also included.

Zoom levels. The T-NASA EMM has 5 user-selectable zoom levels that can be switched at any time at the pilot s discretion during ground taxi. The views to choose from include a fixed, north-up 2-D plan/overhead view that includes the entire airport surface, much like a current paper chart. There are also four 3-D perspective views from an eye point above and behind the ownship position (see Figure 3). Their accompanying measurements are also shown (see Figure 4).

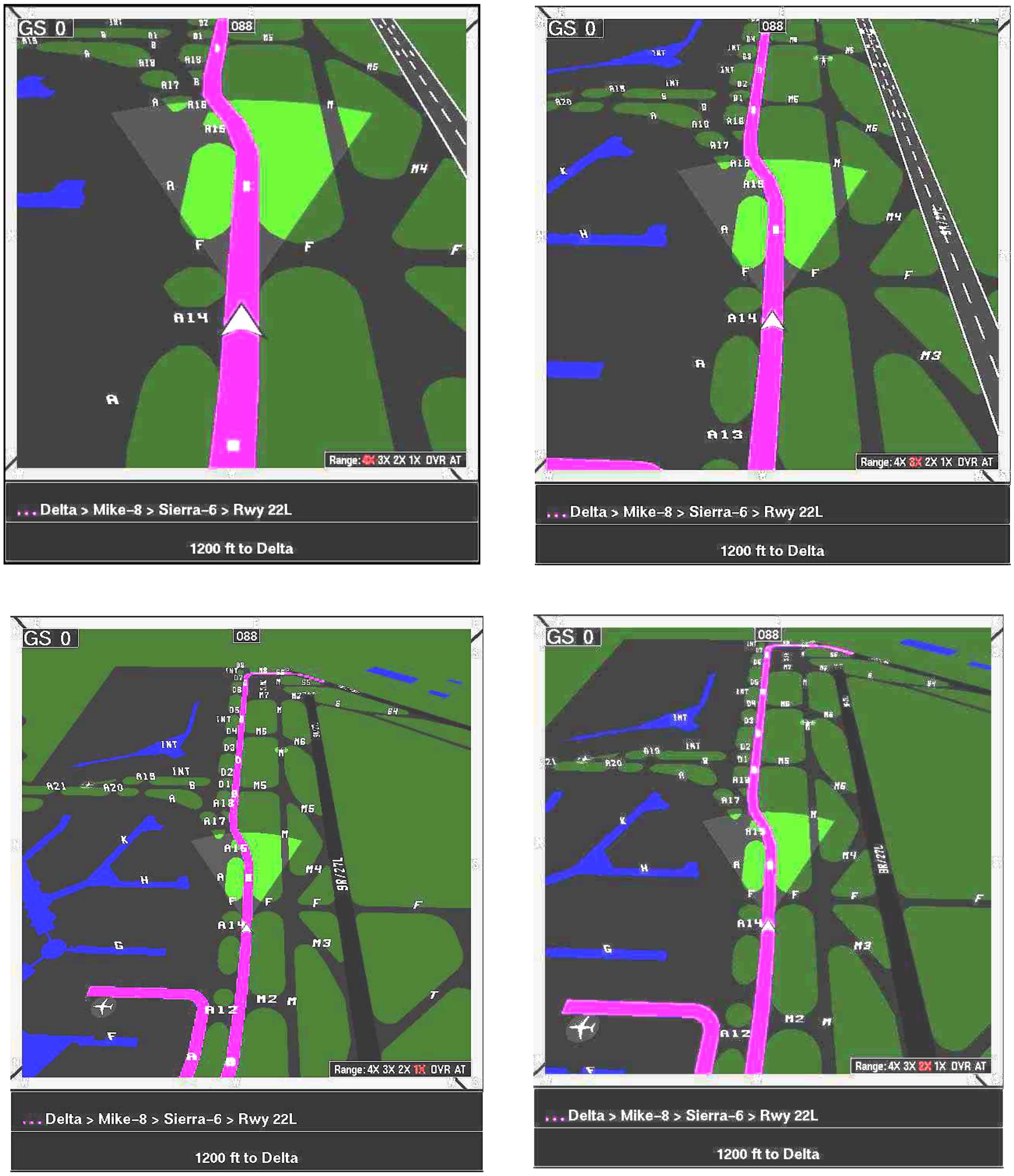


Figure 3. EMM 3-D perspective views. Moving clockwise starting from the top left photograph, zoom levels 4X, 3X, 2X, and 1X.

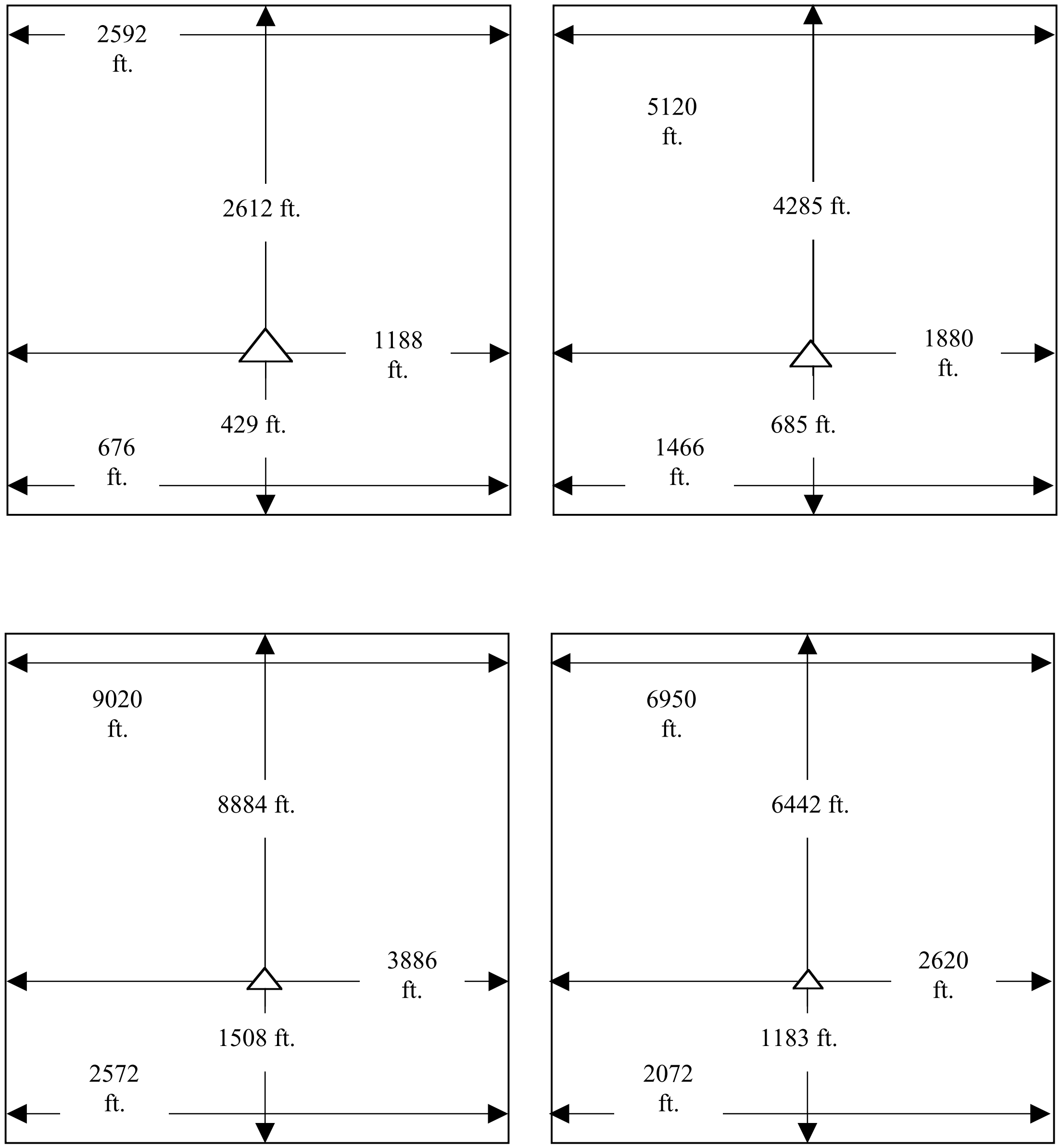


Figure 4. Measurements of EMM 3-D perspective views. Moving clockwise starting from the top left graphic, zoom levels 4X, 3X, 2X, and 1X.

Data Analysis

To measure the safety aspect of taxiing while adding callout modes, the results of taxi performance using each callout was analyzed. In addition, the behavioral eye tracking data were scrutinized to see if callouts decreased the amount of head-down time associated with the EMM display. Also of interest was whether the best taxi performance actually matched the subject stated preferred callout mode. To check the callout modes against the baseline of no callouts given, a single factor, 5-level ANOVA was performed. To compare results of callout conditions to the eye tracking and performance data, a 2 (callout mode: visual callout, auditory callout) X 2 (callout specificity: general, specific) ANOVA was performed.

RESULTS

To analyze the data, a repeated measures full-factorial Analysis of Variance (ANOVA) was conducted. All independent variables--callout modes (visual and auditory) and callout specificities (general and specific)-- were within-participants variables. For the eye tracking and performance data a single factor, 5-level ANOVA was conducted for comparing callout modes to the control condition of no callouts. An ANOVA was then conducted to examine the specific differences between callout modes and specificity. Alpha for all ANOVA s and post hoc tests was set at .05.

The analyses began by reviewing the performance data of percent time on route, mean moving speed, navigation errors and incursions missed. The analyses then moved to the behavioral eye tracking data to assess the effect of callout modes and callout specificities on visual attention. Finally, subjective survey data on callout guidance preference was analyzed. The subjective data was also examined in conjunction with the objective eye tracking data to verify survey responses. The interview questions were analyzed individually, in conjunction with each other, and in conjunction with the objective eye tracking data.

Performance Data

Mean taxi speed. The ANOVA did not reveal a significant main effect for mean taxi speed, $F(4, 56) = 1.66$, $p=.17$. All mean taxi speeds were within one standard error of one another (see Table 2).

A positive finding for this study was the mean taxi speed for the entire route for the baseline condition of no callouts given was 12.75 kts. This speed was within one standard deviation of the taxi speeds found by Graeber and Andre (1998) and McCann et al. (1996, 1997) in their studies using the T-NASA system.

Table 2

Mean Taxi Speeds per Callout Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Mean taxi speed (in kts. per hour)	12.75	12.24	12.51	12.10	13.08

Navigation errors. Navigation errors consisted of errors of either of omission or commission: when a pilot missed a turn or neglected to turn and went onto a taxiway that they were not cleared to be on. This tally included errors whether the pilots later corrected them or not. The single-factor level ANOVA for navigation errors committed did not reveal a significant main effect, F (4, 56) = .61, p = .66 (see Table 3). The number of navigation errors did not correlate with taxi speed.

Table 3

Number of Navigation Errors per Callout Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Number of navigation errors	10	8	5	9	8

Percent of trial 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 course were considered off route. In addition, the width of the taxiway was used to define on route for pad areas and runways.

There was almost no difference observed of the percent of trial on route between conditions (see Table 4). The main effect for percent time on route did not reach significance, F (4, 56) = 1.37, p = .25.

Table 4

Percent of Trial on Cleared Route per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Percent of trial on cleared route	99.10	98.42	99.30	98.52	98.76

Missed incursion responses. There were 75 preplanned incursion trails in this study, with 5 incursion incidences per subject, 1 per each block of 5 trials. Out of the 75 incursion incidences, 8 were not responded to (see 5).

The ANOVA for the number of missed incursion responses was significant, $\underline{F}$ (4, 56)= 5.44, $\underline{p}$<.01. This effect shows that the number of missed incursions in the baseline (no callout) condition was greater than any of the callout conditions, as a separate 2X2 ANOVA found no significant differences between the callout conditions.

Table 5

Missed Incursion Responses per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Missed incursion responses	6	0	0	1	1

Behavioral Eye Tracking Data

Number of dwells by location. The ANOVA for the number of dwells OTW did not reveal a significant main effect, F (4, 56)=0.475, p = .75. The main effect for number of dwells on the EMM was also not statistically significant, F (4, 56) = 1.86, p = .13. The number of dwells on the VC did reach significance, F (4, 56) =16.43, p<.01, however this is to be expected since there is no visual callout under the audio callout conditions.

Despite not finding a significant main effect, we can look at the means from the analysis and extract some usage patterns, best revealed in Table 6 below. Note that the relative number of dwells OTW vs. the EMM is highest for the callout conditions and lowest for the no callout. The specific visual and audio callouts showed the greatest differences compared to the baseline no callout condition.

Note that the numbers in the table below, as with all measures collected with the eye tracker, indicate that the system recorded a dwell on the VC display. Dwells were recorded here even if the subject was under an experimental condition where looking at the VC was not necessary, as there was not a visual callout displayed (e.g. an audio condition). The reason for recording a dwell can be explained by two facts: either the subject s glance passed through the space occupied by the VC while transitioning from looking at the EMM to the OTW display or visa versa, or the subject could have been looking at the space just next to the VC display and the eye tracker erroneously tallied this glance as a dwell upon the VC.

Table 6

Mean Number of Dwells by location per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
# dwells OTW $_{mean}$	133.59	132.86	136.38	138.71	130.57
# dwells EMM $_{mean}$	119.67	111.09	110.10	115.23	105.88
Difference	14	21	26	23	25
# dwells VC $_{mean}$	5.72	14.58	19.32	8.19	6.03
Total # of dwells	260.37	258.53	265.81	262.12	242.48

Average time per dwell by location. The main effect of average time per dwell in a head-up position looking OTW over the entire trial was not statistically significant, F (4, 56) = 1.83, p = .14. Average dwell time head down looking at the EMM was also not statistically significant, F (4, 56) = 0.52, p = .73. The average time per dwell looking at the VC did reach significance F (4, 52) = 4.86, p<.01. Like number of dwells, the VC finding is to be expected, as there is no visual callout under the audio callout conditions.

With the above findings of number of dwells we can again look at the means from the analysis for both display locations and extract some usage patterns. There was a non-significant increase in average dwell time OTW over the baseline under all callout conditions, with the audio specific condition showing the highest dwell time. Meanwhile, the average dwell time for the EMM stayed relatively constant across conditions (see Table 7).

The present study found participants under the baseline no callout condition dwelled OTW a mean of 1.60 seconds and on the EMM 1.26 seconds, as opposed to Graeber s 1998 findings of 2.10 seconds OTW and 1.40 seconds on the EMM under similar conditions. The difference in the OTW time can be attributed to the fact that the eye tracker in this experiment did not analyze the side windows, as they did in Graeber s study. Some refinement of the eye tracker has also taken place since the previous experiment, eliminating time from dwells that should have been attributed to eye blinks.

Table 7

Average Dwell Time by Location per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Average dwell OTW (sec.)	1.60	1.68	1.65	1.69	1.81
Average dwell EMM (sec.)	1.26	1.23	1.21	1.22	1.26
Average dwell VC (sec.)	0.41	0.43	0.59	0.44	0.39

Percent of trial dwelling by location. The ANOVA for percent of trial dwelling OTW did not reveal a significant main effect, F (4, 56) = .99, p = .42. The percent of trial dwelling on the EMM did reach significance, F (4, 56) = 2.54, p<.05. Again, there was a significant effect for the VC location, F (4, 56)=6.53, p<.01.

The findings of percent of trial dwelling by location generally reflected the amount of time pilots attended (looked) OTW versus at the EMM. With the inclusion of callouts, percent dwell OTW went up while percent dwell on the EMM went down (see Table 8 and Figure 5).

The finding of 35.60 percent dwell on the EMM during the no callouts condition is very similar to Graeber and Andre s 1999 finding of 37.70 percent dwell time for his Day 700 RVR condition. Note that the percent dwell times add up to approximately 80 to 85 % across each condition, not 100%. The missing data is attributed to either eye blinks, times when the subject is looking at his hands manipulating the controls, at his feet, etc., and the fact that the eye tracker did not analyze the dwell time the subject spent looking at the side windows/monitors of the simulator.

Table 8

Percent of trial dwelling by location per condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
% dwell time OTW	0.49	0.50	0.51	0.51	0.53
% dwell time EMM	0.36	0.33	0.32	0.32	0.31
% dwell time VC	0.01	0.02	0.03	0.01	0.01

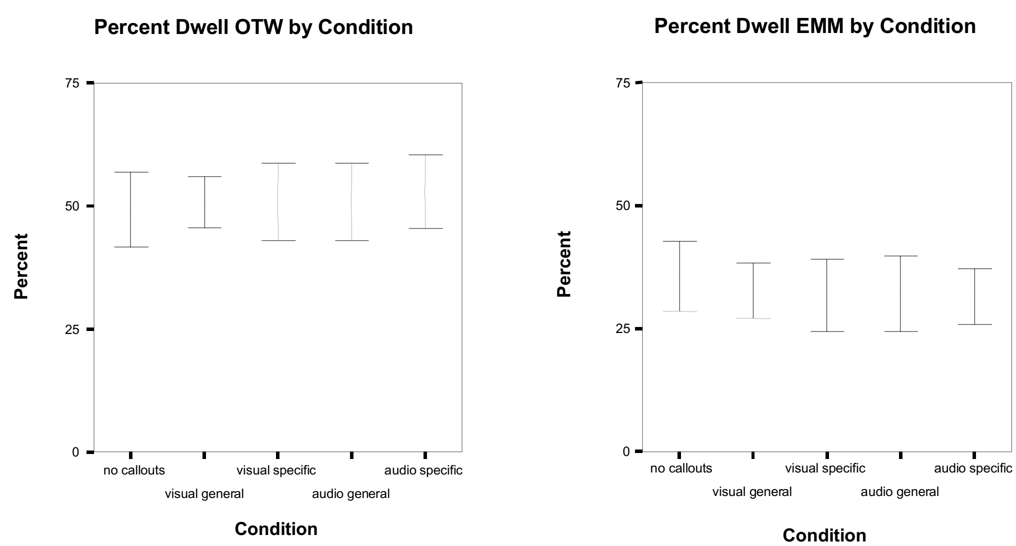
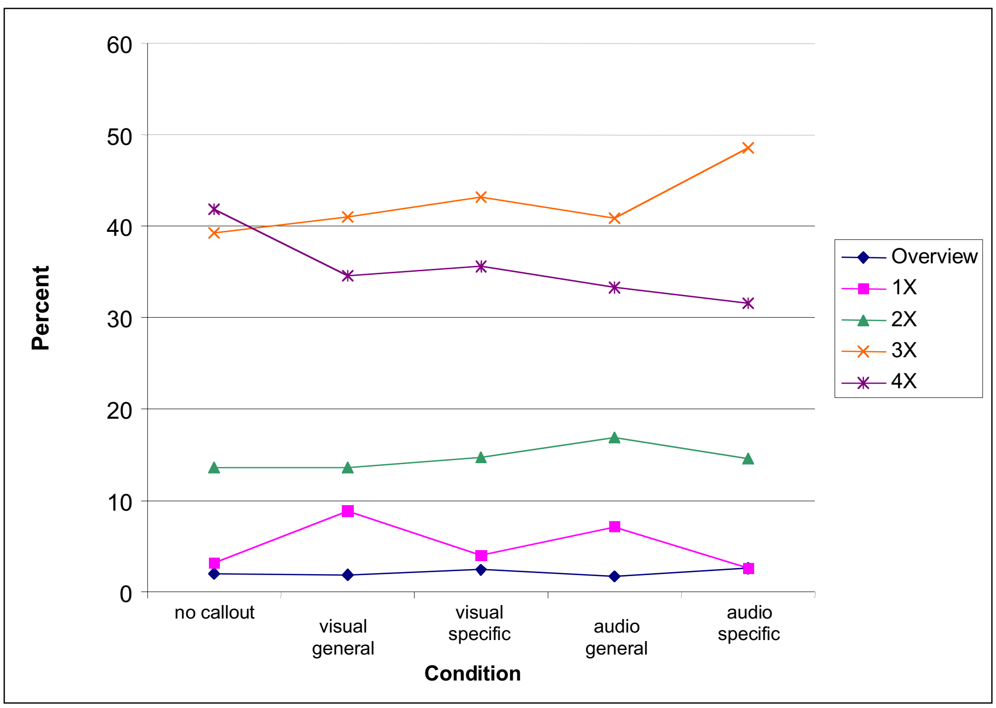


Figure 5. Percent of trial dwelling by location per condition. Percent time dwelling OTW is shown on the left, percent time dwelling EMM is shown on the right.

<u>Zoom level usage</u>. The ANOVA for percentage of zoom level used per condition did not reveal a significant main effect for any zoom level.

Although significant main effects or interactions were not found again, we can look at the means from the analysis and extract some zoom level usage patterns (see Figure 6). With the addition of callouts, the means for percentage of zoom level used for the 1X, 2X, and 3X levels tended to slightly increase (especially the 3X visual and audio specific callouts), while the 4X level use decreased among all conditions (see Table 9).



<u>Figure 6</u>. Zoom level use by condition.

Table 9

Zoom Level Percent Usage per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific	Overall Average %
Overhead %	01.95	01.92	02.44	01.78	02.55	02.13
1X %	03.17	08.85	04.04	07.17	02.61	05.17
2X %	13.53	13.56	14.70	16.87	14.50	14.63
3X %	39.30	41.02	43.08	40.91	48.63	42.59
4X %	41.93	34.61	35.62	33.23	31.55	35.39

Subjective Survey Data

The subjective survey data was gathered from questionnaires using a Likert scale with a range from 1 to 7, with 1 representing the lowest amount of the variable in question (e.g., workload), and 7 representing the highest amount.

Head-down Time. For the amount of head-down time each subject felt they experienced per condition, the ANOVA showed a significant main effect, F (4, 56) = 5.260, $p<.01$. The mean values suggest that the pilots felt their head-down time was reduced with the callouts relative to the baseline condition, with the lowest amount of head-down time in the audio specific condition (see Table 10).

Table 10

Subjective Head-down Time Experienced per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Head down time	4.06	3.80	3.27	3.40	3.13

Workload. For the overall workload pilots experienced while completing their taxi task, the ANOVA showed a significant main effect, F (4, 56) = 3.09, $p<.01$. Again, the data show a general decrease in workload with the inclusion of any type of callout, with the greatest reduction in the audio specific condition (see Table 11).

Table 11

Workload Experienced per Condition

	No callout	Visual general	Visual specific	Audio general	Audio specific
Workload	3.73	3.40	3.47	3.33	2.53

Spare mental capacity. After each callout condition, pilots were asked if they believed they had any spare mental capacity performing the taxi task while using the different callout types. The ANOVA did not reveal a statistically significant main effect, F (4, 56)=1.79, p = .14.

While not significant, the trends are in a consistent direction with the head-down time and workload ratings, showing a general increase in spare mental capacity with the inclusion of any type of callout, with the greatest increase in the audio specific condition (see Table 12).

Table 12

Spare Mental Capacity per Condition

	No Callouts	Visual general	Visual specific	Audio general	Audio specific
Spare mental capacity	4.79	5.00	5.33	5.40	5.73

Awareness of upcoming route. The ratings for awareness of the upcoming route did not reach significance, F (4, 56)=1.07, p = .38.

Though significance was not found, in debriefing sessions subjects stated they felt much more aware of their upcoming route with the use of any callout type presented rather than no callout presented at all (see Table 13).

Table 13

Subject Awareness of the Upcoming Route per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Awareness of upcoming route	5.67	5.87	5.80	6.13	6.07

Situational awareness. The ANOVA did not find a statistically significant main effect, F (4, 56) = 1.40, p = .25. Again, however, the trends suggest that the pilots felt they had greater situational awareness with the use of any callout type presented rather than no callout presented at all (see Table 14).

Table 14

Subjective Situational Awareness per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Situational awareness	5.87	6.00	6.20	6.00	6.27

Self - confidence — safety The ANOVA did not reveal a significant main effect, F (4, 56) = .29, p = .82, for the amount of confidence subject s felt they had to taxi the plane safely in each callout condition (see Table 15).

Table 15

Self-confidence to Taxi the Airplane Safely per Condition

Condition	No callouts	Visual general	Visual specific	Audio general	Audio specific
Self-confidence - safety	6.00	5.87	5.80	6.07	5.87

Trust in the EMM. The ANOVA revealed a significant main effect, F (4, 56) = 3.29 $p<.05$. An additional 2 X 2 ANOVA revealed an audio X visual interaction, F (1, 14) = 6.09 $p<.05$ (see Figure 7). For the visual callout condition, trust is higher in the general callout, whereas for the audio callout condition, trust is higher for the specific callout (see Table 16).

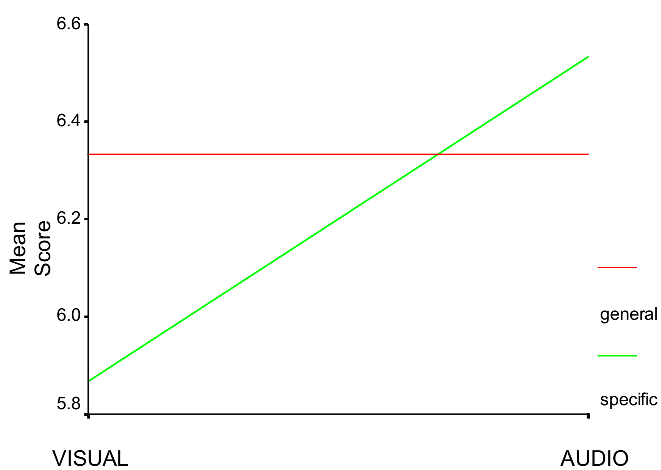


Figure 7. Trust in the EMM - visual X audio interaction.

Table 16

Trust in the EMM per Condition

Condition	No callout	Visual general	Visual specific	Audio general	Audio specific
Trust in EMM	6.40	6.33	5.87	6.33	6.53

Utility. In a post-trial survey asking subjects to compare the utility or usefulness of the callout types presented, the two specific callout types with were found to be of greater use to the pilots than those with general specificity (see Table 17). The ANOVA revealed a significant main effect, F (4, 56) = 4.93, p<.01. An additional 2X2 ANOVA found the specific callout conditions to be rated higher than the general callout conditions, F (1, 14)= 12.80 p<.01.

Table 17

Utility of Callouts per Condition

Condition	No Callouts	Visual General	Visual Specific	Audio General	Audio Specific
Utility (adjusted mean scores)	2.53	2.43	3.86	2.80	3.93

Results Summary

Performance data. As predicted, percent time on route, average moving speed, and navigation errors made were not found to be influenced by the presence or absence of callouts. However, the callouts were effective towards improving incursion detections relative to the baseline condition.

Behavioral eye-tracking data. The results showed that pilots spent a lower proportion of time attending to the EMM when any callout was presented, relative to the baseline condition. Further, the number of dwells on the EMM over the course of an entire trial showed a non-significant decrease with the inclusion of callouts.

Subjective survey data. Pilots stated that with the presence of callouts their workload and amount of head-down time significantly decreased, while trust in the EMM and situational awareness increased. Self-confidence in the ability to safely taxi, spare mental capacity, and awareness of the upcoming route did not significantly change with the inclusion of callouts. When the pilots were asked at the conclusion of the experiment about the utility of the callouts, they stated that they would much rather have one of any type than none at all.

DISCUSSION

In reviewing and interpreting the data, it was found that while not all of the hypotheses were supported, in general the results pointed to the fact that callouts positively affected pilot performance, visual attention and subjective workload.

Performance Measures

The inclusion of callouts showed a difference in two important measured performance events: with the presence of callouts, both the numbers of incursions missed and the number of navigation errors committed decreased. As expected, the average taxi speed and percent time on route did not change with the inclusion of callouts.

In a first look at visual attention allocation to incursion incidents, Graeber and Andre (1999) attempted to find a particular behavioral strategy for using the EMM in incursion situations. Their study included 24 pre-planned incursions, however only 6 were responded to. They hypothesized that even though the subjects stated that the display was helpful in identifying the incurring aircraft s orientation, directing visual attention OTW, and aiding in identifying potential threats, most incursions were not responded to because of the time limits determined by the incursion algorithm, and the fact that pilots might not have been looking at the map at the time the incursion was occurring.

The present experiment both lengthened the algorithm response time and included the callouts to help further direct attention and aid in capturing close calls. By any measure, the inclusion of any type of callout was successful, reducing the number of incursion responses missed by a significant 60 percent over the no callout baseline.

During a post-experiment debrief a subject in this study said he liked the EMM with the (specific) callouts because it directed his scan and freed him to look OTW more.

Behavioral Measures

The results of the behavioral measures were in accordance with our hypotheses. In regards to the EMM, we predicted that the addition of callouts would direct more visual attention OTW, thereby decreasing both the number of EMM eye dwells and the percentage of EMM eye dwell time. Findings suggested that with any type of callout subjects attended OTW for a greater percentage of trial time, while simultaneously subjects attended to the EMM a smaller percentage of trial time.

Zoom level usage. With the presence of callouts, the zoom level usage increased for the percentage of trial allotted to the 3X zoom level while the 4X level use decreased. Post-study interviews revealed that pilots felt that with a callout they did not require as long a time to gain the same near distance information that the 4X level affords. Subsequently they could spend more time at the lower zoom level of 3X and gain better situational awareness by seeing more of the airport surface on the map.

The basic zoom level strategy of the majority of the 15 commercial pilots used was to first check the overview or 1X or 2X zoom levels. This was for two reasons: 1) To cross check the written taxi clearance given them with the route graphic displayed on the EMM, and 2) To gain an awareness of the traffic surrounding them. After this check, they then began to taxi, zooming down to a closer view of 3X or 4X for most of the trial. Occasionally subjects would zoom out to check their SA concerning possible traffic incursions ahead or just to see the remainder of their magenta route. The presence of a callout did not seem to change this basic strategy.

Subjective Measures

Four of the subjective variables measured showed significant effects indicating a positive effect of the callouts: head-down time and workload means decreased, while trust and utility means increased with callouts. As usual, the greatest measured effect was under the audio specific condition; for example, this condition was the only one that showed an increase over the no callout baseline in the case of trust. Similarly, Labiale (as cited in Dingus, Hulse, et al. 1998) in driving task workload studies found that drivers prefer auditory route guidance information over a visual presentation as they feel audio provides a safer system.

Other human factor studies suggest that paradoxically, increasing automation on the flight deck occasionally increased pilot workload (e.g., Damos et al., 1999). The subjects in this experiment however said their workload for completing the taxi task went down with the inclusion of the callouts presented. In addition, subjects felt the amount of head-down time they spent scanning the EMM lessened, while they also felt the callouts were of greater utility and gave them more flexibility over not having a callout at all.

The means for the subjective measure of head-down time and for the objective measure of percent of trial dwelling indicated that what subjects felt (less head-down time) was what happening actually happened (less percentage of trial dwelling on the head down EMM). This correlation of the objective measurement of visual attention and the subjective rating of the same leads us into a closer look at a major concern of this study: the effect callouts would have on subjective situational awareness.

Situational Awareness. Situational awareness has been defined, among other things, as directed consciousness (Smith & Hancock, 1995). The authors of this study argue that SA is the capacity to direct consciousness toward generating competent performance when a person is confronted with a dynamically changing environment. As such SA generates purposeful behavior. If the callouts aid the pilots in directing their attention to critical events, then we should expect to find a positive increase in SA ratings for the callout conditions.

The present study attempted to measure SA along three dimensions, similar to the approach taken by the Selcon and Taylor with their Situational Awareness Rating Technique (SART) (Selcon & Taylor, 1989). The workload rating attempts to determine the demand on resources; the capacity rating attempts to determine the supply of attentional resources, while the awareness ratings attempt to determine the pilot s understanding of the situation. The ratings for these dimensions are provided in Table 18). (To foster comparisons, since workload is a negative score, it has been transformed into a positive score by subtracting it from the maximum rating of 7.).

Table 18

Modified Situational Awareness Rating Technique (SART) Matrix

Construct	**Question**	No callout mean score	Visual general mean score	Visual specific mean score	Audio general mean score	Audio specific mean score
Demand on attentional resources	Workload? (7—score)	3.30	3.60	3.60	3.70	4.50
Supply of attentional resources	Spare mental capacity?	4.80	5.00	5.30	5.40	5.70
Understanding	Awareness of upcoming route?	5.70	5.90	5.80	6.10	6.10
Subjective Situational awareness	Situational awareness?	**5.90**	**6.00**	**6.20**	**6.00**	**6.30**

There was an obvious increase across all 3 dimensions in each callout condition over the baseline, and again the greatest difference was found under the audio specific condition. Combined, these ratings are consistent with the overall SA ratings shown in the bottom row of the table.

Callout Modality and Specificity

Across most measures of performance, behavior (visual attention) and subjective ratings, the results showed the greatest benefits for the audio specific condition. For example, post-hoc pair-wise ANOVAs for the audio specific condition vs. the no callout baseline condition showed the number of dwells and the percent of trial dwelling on the EMM significantly decreased.

Callouts given by voice theoretically have the potential to increase the head-up time looking at the OTW display while decreasing time spent head-down looking at the EMM. Wickens (1992) argues that modality separation of concurrent tasks can make time-sharing in working memory more efficient. Thus the task of taxiing the airport surface a visual task and processing the audio callouts an auditory task, are more easily time-shared relative to the condition where a visual callout is presented. The difference in modality of information sources explains much of the advantages shown by the audio specific condition.

Limitations

Lee et al. (1999) pointed out that command messages (e.g., turn right here) can lead to an automation bias and an unsafe condition. Command messages can reduce certain information processing requirements of the driving task (e.g., perception of relevant information, integration of multiple resources of driving information, and complex decision-making), but it also has the potential to misdirect drivers should the command fail to consider all the relevant factors. Thus, there is a potential for command type cues, such as the specific callouts used in the present study, to be blindly acted upon;

a situation that can be problematic especially if the callouts are unreliable or erroneous. This issue was not examined directly in this study and should be further investigated.

Implications

During post-experiment debrief sessions many subjects pointed to a similar, real-world problem: while audio specific callouts were shown to be most beneficial, the flight deck is a noisy and somewhat confusing environment during the taxi phase. The information from an audio callout would be in danger of becoming lost amidst the many auditory enunciators and conversations, or preempting some other critical task (Wickens, 1992). An alternative suggestion would be a visual specific callout for turns and both an audio and visual callouts for incursion and hold events. One subject, a flight instructor for a major airline, wanted both audio and visual callouts for any change out of the ordinary (which included upcoming holds and incursions) similar to Green s recommendations (Green, Levison, et al., 1993). Another subject Would have liked the audio callout for holds and incursions , and let him decide on the turns: the (audio) turn callouts he found to be annoying. Psychological and human factors theory supports this idea: the visual modality has more autonomy in cognitive interpretation and subsequent response than an audio callout, and Dingus and Hulse (1993) recommend that the auditory modality be used as a prompt for a visual display of changing or upcoming information.

This alternative however does not take advantage of the benefits that using only the audio specific condition brings. A previous study on the T-NASA with datalink systems and their introduction into landing operations considered two approaches

(Hooey, Foyle, Andre, & Parke, 2000). The first was a near-term introductory period in which the T-NASA and datalink systems were added to current day operations, and these technologies would serve as a redundant source of information to voice communication. Also investigated was a longer-term, more futuristic approach, which would require substantial changes to current day operations including datalink only communications in order to take greater advantage of the efficiency benefits offered by T-NASA. This more sterile flight deck environment for the taxi phase of flight would be paramount for audio specific callout use. Accordingly, until datalink communication can reduce the noise level in the cockpit during the taxi phase, a visual specific callout appears as the most viable current option.

Future studies on using callouts with the T-NASA system should include a more realistic simulation of cockpit distractions while taxiing, perhaps involving a secondary and even a tertiary task. Also needed is research into the question of what happens to user trust when the T-NASA system fails occasionally.

CONCLUSION

This study was a preliminary assessment of the influence of audio and visual general and specific callouts on pilot visual attention while using an EMM for taxiing in low visibility conditions. The potential for pilots to use the EMM for aircraft control and to rely too heavily on the display was the major concern and the primary reason for the study. The results tell us that the EMM with the inclusion of callouts affords proper usage of the display as a secondary navigation aid. Data from the current study suggested that callouts direct visual attention OTW while producing shorter glances at the EMM while also aiding pilots in detecting and responding to critical events, such as incursions.

The attentional process of currently taxiing with or without an EMM is more internally goal-driven, with user-defined scanning and repeated, frequent glances. The use of callouts in conjunction with an EMM and the T-NASA system made the navigation task a more external, event-driven process and reduced the need for pilots to constantly scan the EMM looking for events. Audio specific callouts generally scored the highest for any variable measured, however the presence or absence of callouts had a greater effect than the level of specificity and to a large extent, even modality.

Overall, the introduction of attentional callouts for EMM produced the venerable free lunch effect. The callouts had the effect of reducing visual attention to the EMM while at the same time improving route navigation and response to incursion events. We are confident that the use of attentional callouts can be an effective method for maximizing the utility of the EMM display, while minimizing the visual attention impact during the critical taxi phase.

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Appendix A. Consent Form.

AGREEMENT TO PARTICIPATE IN RESEARCH AT SAN JOSE STATE UNIVERSITY

Responsible Investigator: Tony Andre, Professor, and Kevin Purcell

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 risks are 1) minimal eye strain equivalent to what might occur from 1 hours work on a computer, and/or 2) the experiencing of motion (simulator) sickness. 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 26 trials. 25 trials will be broken into five blocks of 5 trials, each block should last no more than 30 minutes. Between the five blocks of trials a twenty minute break will be given; the entire procedure should take 6 hours.

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 Kevin Purcell 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 Nabil Ibrahim (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 B. 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? _________

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

6. How many hours have you logged in a simulator? _______

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

8. Have you ever flown as a flight deck crew member into or out of Chicago O'Hare airport? Yes_____ No______

9. How familiar are you with the O'Hare airport layout?
Very ______ Moderately_____ Slightly______

10. Your experience in control of the aircraft while taxiing O'Hare is:
______not very experienced _____moderately experienced ______very

experienced

11. Your experience in control of the aircraft while taxiing at O'Hare in **low**

visibility is:

______not very experienced _____moderately experienced ______very

experienced

12. How many hours experience do you have in:

Glass Cockpits ______ hours

Traditional Cockpits ________hours

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

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

Vehicle________

15. Have you ever used a Heads-Up Display before?(including cars) _____yes_____no.

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

Vehicle________

16. Do you wear reading glasses or contacts? ______yes______no

17. Age _________

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

19. Your overall experience in control of the aircraft while taxiing is:

______not very experienced _____moderately experienced ______very experienced

20. Your overall experience in control of the aircraft while taxiing in **low visibility** is

______not very experienced _____moderately experienced ______very experienced

Appendix C. General Instructions.

<u>General Instructions</u>

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 **E**lectronic **M**oving **M**ap (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 **T**axiway **N**avigation **A**nd **S**ituation **A**wareness (**T**-**NASA**) display suite under the auspices of Terminal Area Productivity (TAP). TAP is 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 twenty five '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 would in an operational setting. You will be taxiing under a visibility level of 700 RVR during a daytime condition.

Today you will be testing the EMM both with and without a number of automated audio and visual callouts designed to enhance the display s utility. These callouts will announce upcoming turns, holds, possible and imminent incursions.

Procedure

The first thing you will do is participate in a practice trial designed to familiarize you with the handling characteristics of the simulator, the EMM, and the EMM s input devices. You will also experience the four different types of turn callouts we will be testing today. 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 inch of the EMM (you will become familiar with this display during the practice trial). 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 accurately, safely, and quickly 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 consists of 25 trials, broken down into five blocks of five trials. With each new block of five trials a different audio or visual callout display will introduced, with a short survey given to you after each block. You can take a rest break whenever it s requested.

Throughout the study, your goals should be to:

- Taxi as you would under similar conditions, 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.
- Incursions are traffic that are within an designated area and travelling in a certain direction so that they might lead to an accident. A route generating computer using smart algorithms will keep track of your route, other aircraft s routes, and give you constant updates of current positions. If the computer detects a possible upcoming incursion to your ownship you will be alerted by a TCAS style Traffic Advisory,

given to you by either an audio or visual display. If the probable incursion continues into an imminent incursion you will further be alerted by a Collision Warning, again by either an audio or visual display. These incursions may or may not happen while you are participating in the experiment.

- If your cleared route crosses a runway, you are cleared to cross that runway without stopping. If there is traffic landing, taking off, or crossing any runway the same route generating computer will place red bars around that runway to alert you of runway traffic. Also, once your route guides you onto the proper runway you are cleared to take off.

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.

Appendix D. 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. This is what the EMM looks like:

(figure1).

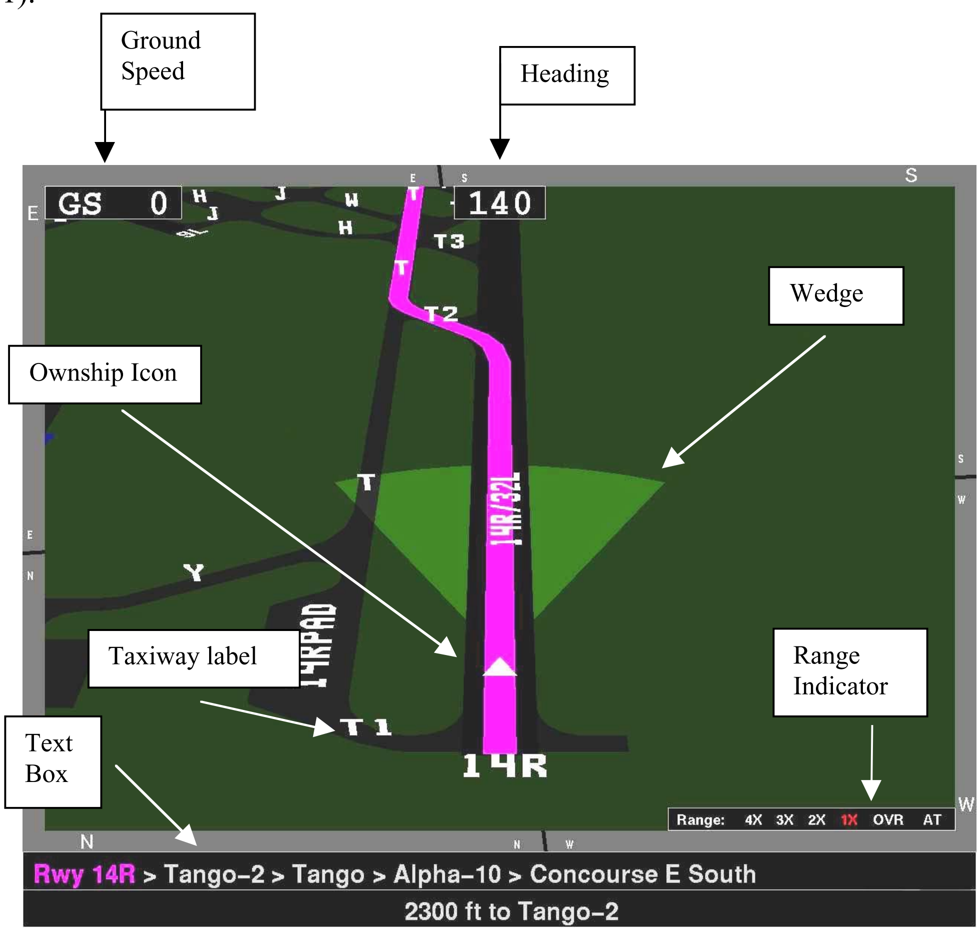


Figure 1. Showing heading, ownship icon, wedge, range level indicator, text box, route guidance, ground speed, taxiway labels.

- **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 overview modes are fixed in a North-up orientation.
- **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. (See Figure 1).
- **Compass Bars / Heading**: The EMM provides two heading cues. The first cue is the heading bars that frame the EMM. These heading bars are colored gray, 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. This icon will always be centered and a third from the bottom of the screen (See Figure 1).
- **Wedge of Importance**: The wedge of importance represents the area of interest in front of the aircraft and extends 1,250 feet. (See Figure 1).
- **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. There are 4 different zoom levels; the zoom level you use is also left to your discretion (See Figure 1).

- **Text box**: The route clearance is presented in the text box that comprises the bottom 1 of the display. This box is divided into 2 rows. The top row contains the textural read out of the taxi route clearance given to you by ATC. This text is colored white except for the portion of the route you are currently on, which will be colored magenta. For those taxi clearances that are too long to show on the entire EMM screen a thumb wheel located on the throttle lever end will scroll the text for you so you can see your entire route. The bottom row contains distance information to your next turn (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).
- **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 in a track-up mode so they rotate to stay up right as you navigate the airport surface. (see Figure 1).

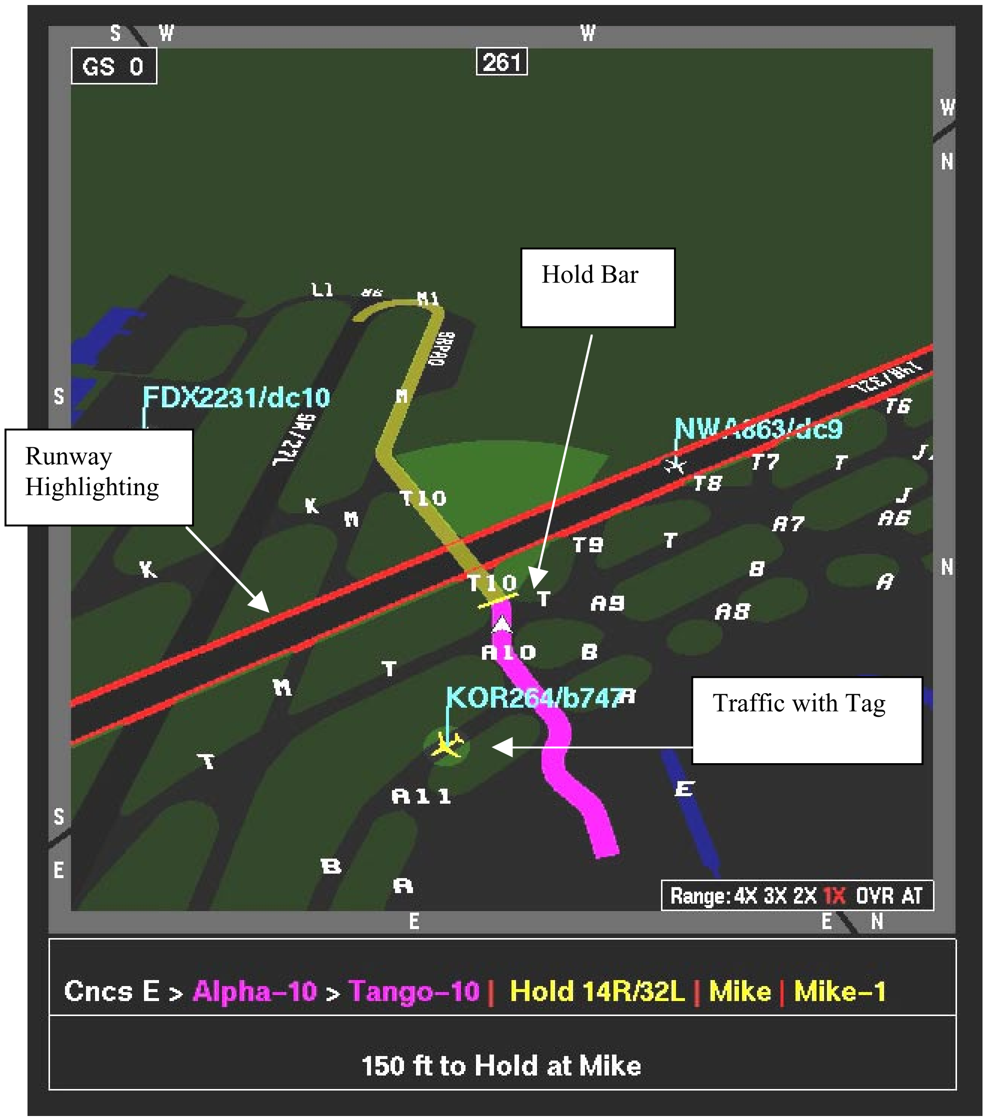
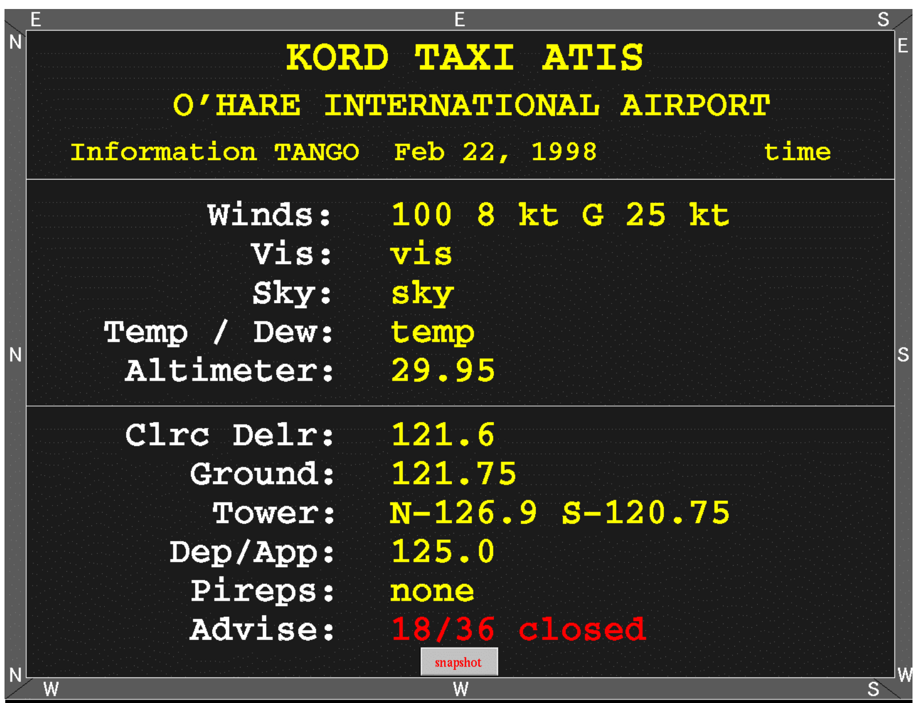


Figure 2. Showing Hold bar, traffic with tag, yellow aircraft icon, and runway highlighting.

- **Hold Bars**: These are yellow bars that appear in front of an aircraft, either the OS icon or traffic icon, that is NOT cleared to cross through an intersection where an 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 magenta route guidance will turn yellow beyond the hold bar. Once a hold bar is removed the magenta route will return and you are cleared to cross through that intersection (see Figure 2).
- **Traffic**: White moving and stationary aircraft icons represent traffic and are updated in real time.
- During a **possible incursion** (within 1250) the piece of traffic in question will turn yellow (see Figure 2).
- During an **impending incursion** (within 300 or 12 seconds) the incurring piece of traffic s icon will turn red and begin to flash.
- **Traffic Tags**: The traffic tags display call sign and aircraft type, for example, DAL109/B737 (See Figure 1). These tags will be visible only when an aircraft is within your 1250 wedge of importance.
- **Traffic Modes**: There are 2 different traffic modes you can switch between at your discretion, normal and declutter.
- **Normal mode:** All aircraft over the entire airport surface will have their icons displayed on the EMM.

- **Declutter mode:** A light circle with a radius of 1250 feet will be shown around your aircraft to indicate you are in declutter mode. Only aircraft within this immediate vicinity will be shown except for traffic on runways. Aircraft on runways always appear on the map no matter which mode you are in.
- **Runway Highlighting:** A runway that is currently occupied (whether the aircraft is landing, taking off, or crossing) will be highlighted in red bars.
- **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, etc.



Appendix E. EMM Usage Instructions.

EMM Usage Instructions

The Electronic Moving Map (EMM) display has been carefully designed 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.

Notifications

- Upcoming hold shorts and proceeds. All ATC directed holds will appear as yellow bars in front of an aircraft, either the OS icon or traffic icon, that is NOT cleared to cross through an intersection. 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 magenta route guidance will turn yellow beyond the hold bar. Once a hold bar is removed the magenta route will return and you are cleared to cross through that intersection and continue.
- Possible and impending traffic incursions. All traffic icons that come within 1250 of your ownship will turn yellow on the EMM. Traffic that is judged to be on an intercept course and comes to within 300 or 12 seconds to a collision will be flashing red. Once the icon flashes red you will be given a 5 second opportunity to press a

button on the tiller joystick (left or right) that corresponds to the direction (left or right) the incursion is coming from. If the proper button is pressed in the allotted amount of time, the incurring aircraft will be given a hold bar and stopped, and you will be given a message to proceed. If you do not press the proper button in the allotted time, your ownship will be given a hold bar and the incurring aircraft will be allowed to proceed.

Appendix F. Callout mode/specificity instructions — Audio general callouts.

EMM Usage Instructions

General Audio Callouts

The following is a brief set of instructions that explain how the EMM, in conjunction with general audio callouts, should be used during taxi.

To aid you in maintaining eyes-OTW as much as possible, an audible callout will notify you to check your EMM. Our objective is to reduce or alleviate your need to constantly check the map for significant events or conditions. Thus, the callout is used to inform you when you should attend to the map. The general audio callout will tell you to Check Map whenever pertinent information is made available or updated on your EMM. This callout takes place before upcoming right or left turns (for example before a turn onto Alpha 15), but after you pass the preceding centerline turn of Alpha 16. You will also receive Hold Shorts and Proceed Across , Traffic Advisory of possible incursions, and Collision Warning of imminent incursions by audible callout. Remember that all traffic icons that come within 1250 turn yellow on the EMM, however those that turn yellow AND are on a possible intercept course with your OS (as judged by a computer algorithm) will be accompanied by an audible advisory callout. Traffic icons that come within 300 or 12 sec. to collision will flash red and be accompanied by an audible warning callout. Once the icon flashes red you will be given a 5 second opportunity to press a button on the tiller joystick (right or left) that corresponds to the direction the incursion is coming from. If the proper button is pressed in the allotted amount of time, the incurring aircraft will be given a hold bar and stopped, and you will be given a message to proceed. If you do not press the proper button in the allotted time, your ownship will be given a hold bar and the incurring aircraft will be allowed to proceed.

You will always receive an audio callout before you need to take one of these actions. Please keep this in mind while using the EMM for this block of five trials, and let the experimenter know when you are ready to begin.

Appendix G. Callout mode/specificity instructions — Audio specific callouts.

EMM Usage Instructions

Specific Audio Callouts

The following is a brief set of instructions that explain how the EMM, in conjunction with specific audio callouts, should be used during taxi.

To aid your task, an audio callout will notify you of:

- Upcoming right or left turns. An example is Turn Left onto Alpha 15.   The callout will be given to you before your Alpha 15 centerline turns, but after you pass the preceding centerline turn of Alpha 16.
- Upcoming hold shorts and proceeds. All ATC directed holds and proceeds will be called out. An example is Hold Short of Tango 3.   Once your route is clear a message to continue you will be given a Proceed across Tango 3.
- Possible and imminent traffic incursions. All traffic icons that come within 1250 turn yellow on the EMM, however those that turn yellow AND are on a possible intercept course with your OS (as determined by a computer algorithm) will be accompanied by the audible callout Traffic Advisory, traffic on right/left. Traffic that is judged to be on an intercept course and comes to within 300 or 12 seconds to a collision will be flashing red, and be accompanied by the audible traffic warning COLLISION WARNING: TRAFFIC ON RIGHT/LEFT.

Remember once the icon flashes red you will be given a 5 second opportunity to press a button on the tiller joystick (right or left) that corresponds to the direction the incursion is coming from. If the proper button is pressed in the allotted amount of time, the incurring aircraft will be given a hold bar and stopped, and you will be given a message to proceed. If do not press the proper button in the allotted time, your ownship will be given a hold bar and the incurring aircraft will be allowed to proceed.

By introducing these callouts our objective is to reduce or alleviate your need to constantly check the map for significant events or conditions. Thus, the callout is used to inform you when you should attend to the map. You will always receive a visual callout before you need to take one of these actions. Please keep this in mind while using the EMM for this block of five trials, and let the experimenter know when you are ready to begin.

Appendix H. Callout mode/specificity instructions — Visual general callouts.

EMM Usage Instructions

General Visual Callouts

The following is a brief set of instructions that explain how the EMM, in conjunction with general visual callouts, should be used during taxi.

To aid you in maintaining eyes-OTW as much as possible, a text message or callout will appear in the Visual Callout (VC) display, located at the top-left of the glare shield, to notify you to check your EMM. Our objective is to reduce or alleviate your need to constantly check the map for significant events or conditions. Thus, the callout is used to inform you when you should attend to the map. The VC display will read Check Map whenever pertinent information is made available or updated. This callout appears before upcoming right or left turns. You will also receive Hold Short and Proceed Across callouts, Traffic Advisory of possible incursions, and Collision Warning of imminent incursions on the VC display. Remember that all traffic icons that come within 1250 turn yellow on the EMM, however those that turn yellow AND are on a possible intercept course with your OS (as judged by a computer algorithm) will be accompanied by the alert text callout. Traffic icons that come within 300 or 12 sec. to collision will flash red and be accompanied by a text warning callout. Once the icon flashes red you will be given a 5 second opportunity to press a button on the tiller joystick (right or left) that corresponds to the direction the incursion is coming from. If the proper button is pressed in the allotted amount of time, the incurring aircraft will be given a hold bar and stopped, and you will be given a message to proceed. If do not press the proper button in the allotted time, your ownship will be given a hold bar and the incurring aircraft will be allowed to proceed.

You will always receive a visual callout before you need to take one of these actions. Please keep this in mind while using the EMM for this block of five trials, and let the experimenter know when you are ready to begin.

Appendix I. Callout mode/specificity instructions — Visual specific callouts.

EMM Usage Instructions

Specific Visual Callouts

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 aid you in maintaining eyes-OTW as much as possible a text display has been included at the top of the glare shield to notify you of upcoming turns, holds, and possible traffic incursions. This text message alerts you to scanning the EMM to gain its information and situational awareness.

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 J. Callout condition survey.

EMM/Callout Survey

For the EMM/Callout package you just experienced, please rate each of the following dimensions on a scale from 1 to 7:

	1=Very Low					7=Very High
1. Overall workload	**1**	**2**	**3**	**4**	**5**	**6**	**7**
2. Time pressure	**1**	**2**	**3**	**4**	**5**	**6**	**7**
3. Heads-down time	**1**	**2**	**3**	**4**	**5**	**6**	**7**
4. Your confidence in your ability to safely taxi.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
5. Trust in the EMM	**1**	**2**	**3**	**4**	**5**	**6**	**7**
6. Spare mental capacity in this callout condition?	**1**	**2**	**3**	**4**	**5**	**6**	**7**
7. Awareness of the upcoming taxi route?	**1**	**2**	**3**	**4**	**5**	**6**	**7**
8. **Overall Situational Awareness**	**1**	**2**	**3**	**4**	**5**	**6**	**7**

Appendix K. Final callout survey.

Final EMM/Callout Survey

1. For the EMM/Callout packages you just experienced, please rate the utility of each:

1=Low 3=Neutral 5=High

No Callouts	1	2	3	4	5
Visual Specific	1	2	3	4	5
Visual General	1	2	3	4	5
Audio Specific	1	2	3	4	5
Audio General	1	2	3	4	5

2. How often did you read the clearance text in each of these conditions? Please rate each of the callout packages on a scale from 1 to 5:

1= Did not use 3=Neutral 5= Very Often

No Callouts	1	2	3	4	5
Visual Specific	1	2	3	4	5
Visual General	1	2	3	4	5
Audio Specific	1	2	3	4	5
Audio General	1	2	3	4	5

2a) If you did not circle 5 in any of the above conditions, please write down when you read the clearance text and why.

No Callouts

Visual Specific

Visual General

Audio Specific

Audio General

3. In each condition how did you use the EMM (Please circle one)

No Callouts	Visual General	Visual Specific	Audio General	Audio Specific
To control the aircraft	To control the aircraft	To control the aircraft	To control the aircraft	To control the aircraft
As a primary navigation display	As a primary navigation display	As a primary navigation display	As a primary navigation display	As a primary navigation display
As a secondary navigation display	As a secondary navigation display	As a secondary navigation display	As a secondary navigation display	As a secondary navigation display

4. In any condition did you ever feel that you were looking at the map when you should have been looking out the window? (Please circle all that apply)

No Callouts
Visual Specific
Visual General
Audio Specific
Audio General