The Effects of Text and Hybrid Graphic-Text Formats on Pilot Performance Using Flight Deck Data Communication Displays

Ricardo Daniel Muñoz Da Costa
Wright State University

THE EFFECTS OF TEXT AND HYBRID GRAPHIC-TEXT FORMATS ON PILOT PERFORMANCE USING FLIGHT DECK DATA COMMUNICATION DISPLAYS

A Master's thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

By

RICARDO DANIEL MUNOZ DA COSTA

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Ricardo Daniel Munoz Da Costa ENTITLED The Effects of Text and Hybrid Graphic-Text Formats on Pilot Performance Using Flight Deck Data Communication Displays BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering.

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Jennie J. Gallimore, Ph.D.
Thesis Director

____

Thomas N. Hangartner, Ph.D.
Chair, Dept. of Biomedical, Industrial, and Human Factors Engineering

Committee on
Final Examination

____

Jennie J. Gallimore, Ph.D.

____

Clark Shingledecker, Ph.D.

____

Subhashini Ganapathy, Ph.D.

____

R. William Ayres, Ph.D.
Interim Dean, Graduate School

ABSTRACT

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Air Traffic has shown a steady increase since the institution of commercial aviation in the first quarter of the last century, and the use of the United States National Airspace System (NAS) is expected to increase by 45 percent more passengers by the year 2015 (Smith, 2004). The increasing demands of the NAS require preventive measures in order to preserve the safety of operations. NextGen is a transformative program expected to enhance the safety and effectiveness of NAS operations. One of the ways that it will achieve these goals is by improving air-ground communications.

In the current system, communications between pilots and Air Traffic Control (ATC) is accomplished via voice radio; controllers have the task of communicating clearance information to aircraft in their designated airspace. This method of communication proves to be effective when used during urgent situations utilizing short messages. Voice communication can be ineffective and inefficient under various other circumstances. For example, message length and complexity can burden pilot memory. For NextGen, the use of data link allows for the creation of data communication (DataComm) messages and clearances sent directly to flight deck displays, thereby reducing the need for voice. DataComm will enable future communication systems to relieve the pilot from retaining immediate fight path information as it is communicated. This information may overload their cognitive processing abilities resulting in a reduced ability to make accurate and correct decisions.

There have been several studies evaluating the effects of DataComm using textual message displays on the flight deck. To date there is no evidence of major research investigation of the use of graphics and or hybrid techniques for DataComm message display.

The objectives of this research were to investigate the effects of text and graphics formats on pilot interpretation of spatial clearances given en route. Pilot performance was evaluated for five communication formats (TEXT only, Graphics+Text, Graphics+Text+updated UM, Graphics+Text+Altitude Situation Display, and Graphics+Imbedded Text+Altitude Situation Display). The performance measures were time to interpret an uplink message (UM) from ATC, and percentage of correct responses, including correct acceptance and correct rejection of a clearance. The findings indicated that there are statistically significant differences in pilot performance when using graphics to communicate ATC uplink clearances. As the number of elements in a clearance increased, pilot performance with respect to response time and percent correct was significantly improved with combined graphics and text formats compared to a text-only format.

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

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I. INTRODUCTION

"One Look is Worth a Thousand Words" (Barnard, 1921).

Although this phrase has seen its share of uses, the first time that it was put into a practical context was on December 8th, 1921. Fred R. Barnard wrote an article in an advertising trade journal discussing how images enhance the effectiveness of advertisements. Similarly to the way that images improve the effectiveness of advertisements, they are likely to improve on the current voice and text based communications used in air traffic control. When used for lengthy trajectory air traffic control clearances, voice communication becomes cumbersome and wordy, relying heavily on pilot memory to rapidly encode and evaluate the acceptability of the instruction. Although text displays are more persistent than voice, a similar problem arises when displaying lengthy text messages in a data link communications environment as pilots must still reinterpret the linguistic information as a proposed trajectory through space and time in order to evaluate its suitability because of the limitations of traditional display formats, alternatives will be needed to fully support pilots as they begin to deal with the complex ATC messages that will be exchanged in the future National Air Space (NAS) environment The navigation display (ND) on the flight deck of commercial airplanes offers a graphical representation of the aircraft's route of flight and surroundings using a map type format. The ND display includes graphics, icons, and textual information regarding the planes trajectory route and its surroundings. One potential option for displaying DataComm messages in an alternative format would be to use the ND and exploit its ability to condense the information and potentially increase the communications bandwidth by using graphics (Nielsen, 1993).

NextGen - DataComm

NextGen is a program being deployed by the FAA to manage the increasing air traffic demands on the NAS with the goal of sustaining the safety and effectiveness of operations focused on a variety of functions including air-ground communications. A key aspect of the NextGen plan is to incorporate digital communications networks via ground stations and satellites. DataComm allows the flow of data through computer systems. The data link network will include communication between air traffic control and the flight deck reducing the frequency of voice communication. Currently, pilots are required to communicate with ATC through voice radio frequencies to reach agreement on the plane's re-route via dialog with the purpose of accommodating situations such as incoming traffic or weather while simultaneously performing all aircraft navigation tasks. The ND and the primary flight display (PFD) are the primary tools used to navigate through the airspace using ground radar stations (fixes). Pilots view their route in the ND and use the PFD to know and follow the aircraft states. Circumstances such as weather, fuel efficiency, and traffic factors constantly change, thus forcing adjustments to the aircraft's path. Voice communication can be initiated by ATC or the pilot by sending clearance message requests (downlink message) to ATC or ATC sending a clearance message (uplink message) to the pilot. The ND display shows information about the route and the position of the aircraft in relation to the flight path, ground or terrain, while also including some aircraft status information (speed, altitude, direction). The ND display provides a platform to test the negotiating/decision making tools that could improve the Air-to-Ground communication.

The NextGen plan will also adopt the concept of trajectory-based operations (TBO). TBO, as explained by Chang, Andre, and Foyle (2009).

> “constitute a key mechanism of the NextGen ConOps for managing traffic in high-density or high-complexity airspace. Applying this mechanism to surface operations at major airports results in the use of 4-dimensional (4D) trajectories to enable safe and efficient surface operations. When referring to 4D-trajectory (4DT) operations, it is implicitly assumed that there is already agreement between the Air Navigation Service Provider (ANSP) and the flight deck (FD) on a 4D trajectory to be executed; otherwise the notion of 4D trajectories is meaningless. Full 4D trajectories may imply defining 3D spatial position as a function of time.”

DataComm is expected to improve positioning accuracy, enable automation for conflict prediction, and increase flexibility in the management of aircraft trajectories, reducing the dependency on fixed route structures (Smith, 2011). NextGen hopes to meet the demands of the growing air traffic in NAS as new methods of communications are explored and recommended through research. The Using DataComm, ATC will communicate to the pilots during mid-flight by utilizing a set of uplink messages (UM). Uplink messages are created from the SC-214 message set. These messages are created by The Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC-214) whose members are subject matter experts in the aviation community from the United States as well as Europe. This committee created a master document that contains the entire message set utilized for **ground** to **air** communication. Clearances are categorized in two main subsets up-link messages (UM) and down-link messages (DM). There are various types of UMs giving the controller a variety of choices to produce re-routing paths. The UMs are concatenated by ATC to create an uplink clearance messages to be vocally communicated to the pilot. DMs are used by the pilot to send messages or negotiate with ATC. Elements in clearances for navigation include; direction, altitude, speed, and time. There are several possible combinations in which clearances can be concatenated. Controllers retain the power to concatenate the UMs in any way they want from the entire SC-214 message set to communicate with the pilot.

Voice Communications

Voice radio has a limited communication bandwidth. Only one human can speak at time in a simplex system (Nguyen, 2011). In the voice communication process, the controller issues a clearance to the pilot, and then must wait for the pilot's response. Many factors can adversely affect the effectiveness of this simple communications act. Kerns (2009) explains that weak signal strength and interference can cause messages interruptions or loss of voice communication which adds confusion to the dialog process. Brandt (2011) found that pilots are at risk of hearing a similar clearance intended for a different pilot, therefore accepting it and causing a dangerous situation. Brandt (2011) added that pilots often request repeats of clearances, thereby decreasing the efficiency of the communications process. Kerns (2009) noted that microphones are activated by hand and not by voice, and pilots forget to turn off their microphone obstructing the frequency signal to other pilots.

Figure 1 illustrates the current model used for ATC pilot communications; the one way arrows represent the fact that only one person can communicate a specific time.

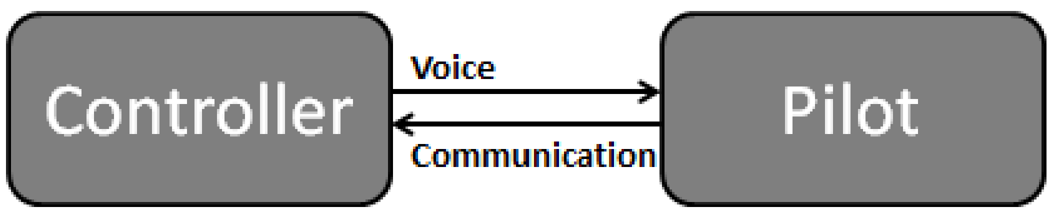


Figure 1 Current Controller-Pilot Communication

Implementing communication through DataComm can increase communication capacity by offering a redundant communications channel and eliminating some of the weaknesses of the voice system. The DataComm system is built upon addressing communication discretely instead of a broadcast voice communication system, allowing the digital transmission of information. Digital transmissions enabled by DataComm systems will improve error checking through the use of internal systems. In the current system, error checking is dependent upon analog systems and the operator’s cognitive ability. The current system also relies on transient voice message limiting the retention capability of the operator; DataComm improves the retention of information through persistent visual flight deck displays.

The long term goal of the NextGen plan is to integrate several data channels that enable communication between **ground** to **air** and **air** to **air** as a single system for NAS communication (see Figure 2). Current clearance negotiation is limited by the location of radio frequencies emitting sources. In contrast, data link computer systems supported by satellite allow the controller to mass communicate with pilots by sending multiple uplink messages to different pilots at one time.

Navigating routes without relying on ground radar fixes opens up a plethora of possibilities regarding the creation of flight plans and in-flight re-routing. On most occasions these radar fixes serve as re-routing waypoints for pilots and controllers to follow when a situation requires an alternate path. NextGen will enable negotiation of time-based clearances with any given point on the map by using the latitude and longitude of the specific location.

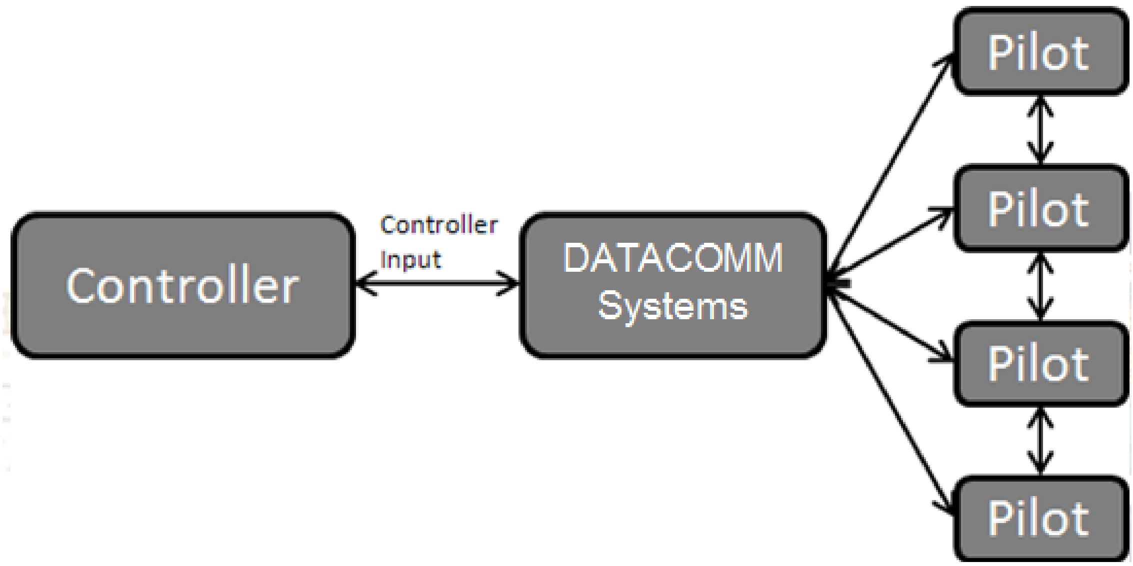


Figure 2 DataComm Increased Bandwidth

II. BACKGROUND

DataComm Text, Voice, and Auditory

DataComm displays using voice and text formats have been investigated in prior research. The literature review conducted by Gallimore, Shingledecker, Tsang, Oh, and Kiss (2011) summarized several of the more relevant studies on clearance communication that compared these formats. For example, Helleberg and Wickens (2003) tested the effectiveness of three different data link interfaces involving auditory (synthesized voice), visual (text messages), and redundant presentation of air traffic control information. Certified flight instructors flew a general aviation flight simulator with full visual display of the outside world. The results indicated that the auditory format had the lowest read back accuracy; showing that voice communication was most prone to error. The findings also indicated that there are different types of human errors related to a voice based communication, such as, miscommunications, interruptions, and misinterpretation. The textual visual display was shown to have the greatest read back accuracy and provided least interference with the higher-priority task of controlling the aircraft. The results showed that text serves as a redundant source of information providing a backup system in case an error occurs during voice communication. The authors stated that the use of combined text and voice enhanced communication in a field environment.

Lancaster and Casali (2008) compared total transaction time using three data communication formats: voice alone, text alone, and a mixture of both voice and text displays. A single pilot flying in a partial task simulator was tested with a dedicated text data link display. The results indicated that communication response time, head down time, and subjective workload were highest when utilizing the visual text format when compared with an auditory digitized speech format and a redundant FORMAT with text and synthesized speech. They also found the voice transaction time to be longer in the mixed FORMAT than in the single medium FORMAT. The researchers indicated that the advantages of voice communications may be limited to specific conditions including situations when clearance communications occur without interruptions from other speakers, when radio transmissions are strong and reliable, and where misinterpretations are unlikely while communicating messages to the pilot. Human performance was dependent on length and complexity of the clearance when communicating messages while using voice and text; text provided redundancy and information retention producing positive outcomes. Lancaster and Casali did not use four dimensional trajectory messages or longer concatenated messages for their experiment. In the current research a variety of messages were tested while using the different communication formats.

For visual communication data Wickens, Goh, Hellegerg, Horrey, and Talleur (2003) found that the head down time required a cost to the higher-priority tasks to aviate and navigate. However, the visual FORMAT had higher read back accuracy than the auditory format (prerecorded speech). This corroborated the finding that persistent text displays provide message backup information in case the pilot was overloaded with the higher priority tasks of aviating and navigating when the transient auditory message arrived. The Gallimore, Shingledecker, Tsang, Oh, and Kiss (2011) review found that the Aeronautical Data Link Integrated Product Team and Human Factors Working Group (1999) and Navarro and Sikorski (1991) synthesized most of the work on DataComm up to 1999 and summarized these findings in Table 1 presented below.

Table 1 DataComm research prior to 2000 (Gallimore, et al., 2011).

Research Issue/Area	**Navarro & Sikorski (1999)**	**DL HF Working Group (1999)**
Reduction of radio bandwidth	X	
Reduction of communication errors	X	
Transaction speed	X	X
Intra-cockpit communication	X	
Party line and situation awareness	X	X
Head down time	X	
Presentation of information & presentation format	X	
Level of automation	X	X
Coding	X	
Priority definition	X	
Communication efficiency		X
Workload		X
Procedures/Protocols		X
User-system interaction		X
Display location		X
Display mode (auditory, text, graphic)		X
When it should be applied (Application)		X

In 2003 Mueller and Lozito conducted a study in a FAA Level D certified 747-400 simulator with FANS 1/A data link capability using the CDU as an interface. They tested two crewmembers in the simulator, the non-flying pilot was asked to handle the communication tasks. The transaction time while using data link was significantly longer than the transaction time while using voice when using the assumed uplink and downlink transmission times of low complexity clearances. Both pilots were requested to read the ATC text uplink clearances from the display. As part of the experiment, pilots were time pressured between messages; with the interval time changing from one minute to five seconds. Pilot performance decreased due to the time pressure, resulting in lengthened data-link transaction times in both single voice or text and mixed voice and text medium formats. Similarly, pilot performance decreased when using voice lengthened transaction time with increased time pressure; but only in the mixed format. In addition, there were more read back errors in the voice condition than in the mixed medium format. Finally, there were four times as many clarification requests in the mixed as in the single medium format. These findings indicate that even with the low accuracy read back in voice, it is still significantly faster than using the data link communication system. Some factors to consider are: the amount of information contained per message as well as the type of datalink display system involved in the experiment. On the other hand McGann, Morrow, Rodvold, and Mackintosh (1998), found no difference in the data-link transaction time even accounting for the time the pilot spent to access the message, read it, and acknowledge it to ATC.

The contrasting and variable results from these studies point out the competing advantages and disadvantages from both auditory-voice and visual-text formats of pilot-controller communication. Each format seems to have a particular advantage with different types of communication setups. The evidence points out that text allow pilots to be more accurate by providing persistent visual information whereas voice does not provide a procedure that enables information retention.

Voice on the other hand, when communication conditions are ideal, allows pilots to complete communication in less time but still requiring several clarifications.

Sharples, Stedmon, Cox, Nicholls, Shuttleworth & Wilson (2007) and Wickens et al., (1998) concluded that for routine communications which include standard clearances and instructions, pilot requests, weather information, airport terminal information services (ATIS) broadcasts, standard changes in the cruise phase of flight and long haul transatlantic flights, textual data shows to be more effective. Voice communications on the other hand would be better utilized in unusual, emergency, or non-procedural exchanges. The NextGen plan targets the implementation of Trajectory Based Operations (TBO) and four dimensional clearances. In the future, clearances will contain more information with increased complexity, enabled by DataComm systems. In addition, voice communication always requires a confirmation to the controller from the pilot. With datalink systems once the UM is sent to the pilot ATC knows that each specific UM has been sent to its correct recipient. The complexity and information parameters required for future clearance communication forces the development of new communication formats other than voice.

In 2010, a literature review was performed to create a Human Factors Research Plan for Flight Deck Data Communications (Cardosi, Lennertz, and Donohoe, 2010). This review was primarily based on studies conducted after 1999. The literature review contains a suggested priority categorization for research (high, medium, low). Table 2 lists all the research areas involved and their respective priority as specified by Gallimore, et. al., (2011).

Table 2 Research priority regarding DataComm (Cardosi, 2010, as specified by Gallimore et. al., 2011)

Research Area	Priority
Analysis of current operations to help identify needed improvements to the current system and ensure optimum interoperability of air and ground systems	High
Complexity of uplink text messages and the interaction with auto versus manual loading of clearances	High
Protocols for use of voice vs. data link in a mixed modality environment	High
Optimum display of complex information	High
Loss of party line information	Medium
Model of communications system performance	Medium
Clearance negotiation using data link	Medium
Use of synthetic speech to annunciate data link messages	Low
Mechanism for monitoring and improving system performance	Low

This study investigated items in two of the high priority marked topics on Table 2. As mentioned, complexity of uplink messages and optimum of display of complex information are both rated as HIGH on the list. There are advantages and disadvantages to the voice and text methods of communication. However there is an unknown array of possibilities to experiment with combining these methods of communications with the use of graphical elements to depict clearance information on the flight deck. The research performed in this study investigated the effects of a hybrid graphic and text when communicating varying complexity messages.

Text and Graphics for DataComm

Wahlster, Andre, Finkler, Profitlich, and Rist (1993) stated “when explaining how to use a technical device, humans will often utilize a combination of language and graphics.” Hybrid multimodal interfaces in years past have performed better than individual mode communication interfaces. Other factors to consider are language and culture. Horton (1993) discussed that "Graphics cannot totally replace words. However, with careful design they can bridge barriers of language and culture."

There is an opportunity to explore human performance using communication formats containing graphics. The NextGen plan requires a new communication system enabled by DataComm displays. Communication improvements between ATC and the pilot may be implemented through different existing systems with innovative communication formats. In the future, airspace traffic will be manipulated with 4D TBO. Future air traffic criteria will take into consideration advance planning, accounting for en-route weather, efficient fuel consumption, and avoiding oversaturation of traffic on routes and near airports. The ND which currently displays graphics for aircraft navigation retains the potential to provide graphic clearance information.

The saying ***"One look is worth a thousand words"*** implies that humans can often perceive information more quickly and accurately through a pictorial and graphical method (Sheikh, 2006). Since 2000, NASA has experimented with NextGen communications concepts that implement graphical displays. Gallimore et. al., (2011) summarized the NASA studies in the following table (Table 3). Most of these studies performed at NASA were powered by state-of-the-art computer systems that enable the use of complex graphics in DataComm displays and are designed for aircraft of the future.

Table 3 Summary of Graphics Studies by NASA (Gallimore, et. al., 2011).

Authors	Focus	Study Type	Display Type		
			Controller	Pilot	DataComm
Hooey, Foyle, & Andre (2000)	Surface Operations	Simulation	None	1. HUD 2. Moving map	Voice, CPDLC, Moving map with route
Prevot, Shelden, Mercer, Kopardekar, Palmer, & Battiste (2003)	Trajectory and Airborne Separation Assistance	Concept/D escription	Controller Radar	CDTI with self-spacing info	None
Smith, Lee, Prevot, Mercer, Palmer, Battiste, & Johnson (2004)	HITL Air-Ground Trajectory Negotiation	Simulation	Enroute controller display,	3D CDTI	CPDLC
Prevot, Callantine, Lee, Mercer, Battiste, Palmer, & Smith (2005)	Co-operative ATM	Concept	NA	NA	None
Prevot, Battiste, Callantine, Kopardekar, Lee, Mercer, Palmer, & Smith (2005)	ATC Tools, lessons learned	Concepts, reviews previous simulation s	ATC tools	Traffic display (not shown)	Route & speed text uplinks only. Comm in voice
Williams, Hooey, & Foyle (2006)	Surface Operations 4D taxi clearances	Simulation	None	1. HUD 2. Electronic map with graphical clearance	None
Muller (2007)	Data link & automation strategic trajectory concept	Simulation	Center-TRACON Automation System (CTAS) display single waypoint strategic trajectory in trial planning phase (vertical)	1. Control display unit (CDU) text. 2. New traj auto loaded onto pilot navigation display	CPDLC
Battiste, Johnson, Johnson, Granada, & Dao (2007)	Cockpit situation display for 4D enroute and arrival merging/sp acing	Descriptio n, design approach, subjective ratings from pilots	None	Cockpit situation display (CSD)	None
Prinzel, Jones, Shelton, Arthur, Bailey, Allamandola, Foyle & Hooey, (2009)	4DT and Surface Operations	Descriptio ns	NA	1. Nav display set to surface map. 2. HUD	None

Authors	Focus	Study Type	Display Type	Authors	Focus
Cheng, Andre, & Foyle (2009)	Surface Operations	Simulation	NA	Flight deck automation for reliable ground operations (FARGO) HUD	Downlinked text message and creation of graphics of clearance on HUD
Shelton, Prinzel Jones, Allamandola, Arthur & Bailey (2009).	Surface Operations	Descriptio n / brief review previous studies	None	Primary flight display, Navigation Display, HUD	Text ATC clearances, Electronic flight bag (text)
Comstock, Baxley, Norman, Ellis, Adams, … Williams (2010)	DataComm High Density Terminal Areas	Simulation	None	1. Text clearances 2. Moving map 3. Moving map with route	Voice and CPDLC

Battiste et.al. (2007), as illustrated in Figure 3, tested a display that incorporated the use of a three-dimensional perspective in a navigation display (ND). At the top of the display, information about the aircraft states and aircraft route is exhibited. The traditional map view of the ND was replaced by the complex and advanced three dimensional perspective maps. This map uses sophisticated software to produce the graphics that show the aircraft path in relation to traffic, terrain, and general situation awareness. Pilots rated this three dimensional display to be acceptable and easy to use. Pilots gave feedback on a 5 point scale (1 = very difficult, 2 = difficult, 3 = acceptable, 4 = easy, 5 = very easy); pilots as a mean average awarded a 3.5 for ease of use and a 4 for usability. In a similar study Arik-Quang V. Dao, Battiste, and Granada-Vigil (2006) allowed the pilots to switch between two dimensional and three dimensional modes within the CSD. Subjective feedback revealed that when the tasks contained a heavier mental workload pilots had a harder time deciphering information and therefore preferred the two dimensional mode for heavier workloads. Both of these studies imply that graphics can be used as a decision aid successfully when displaying information on flight deck displays. Per subjective input there is an indication that minimal graphics are preferred while managing heavier workloads.

Figure 3 NASA CSD. Perspective view with traffic and conflict from Battiste et al. (2007).

In 1993 Neilson and Lee said that "a graphical depiction may provide a context for linguistic interpretation, especially in respect of the disambiguation of special expression, graphical expressions (pictures and drawings) themselves require a context-dependent interpretation which, itself, can derive from an accompanying natural language expression." 4D clearances pose a degree of difficulty to mentally project all elements correctly onto an imaginary alternate route (mental model) while inflight. As an analogy, clearances are much like another language, the NAS language, and graphics have historically bridged the communication gap between languages. Perhaps graphics, if used in context, hold the power to disambiguate and provide linguistic interpretation for pilots when interpreting uplink messages. Graphics are already available in the flight deck. In the 1960's the flight director was implemented. Ellis, Kaiser, and Grunwald in 1993 explain this dynamic:

> "Flight directors, which came into widespread airline use in the 1960's aid the pilot in achieving improved performance by combining the error and the error rate information; producing a control command appropriate to the situation. This command is then compared with the existing control input and the difference displayed as a steering command."

In Figure 4 the flight director is represented by the pink-empty geometric triangle and the actual position of the plane is the black-filled arrow. This picture shows an example that tells the pilot the plane should rise to the level of the pink level indicator. These graphics have successfully aided the pilots to acquire a higher situational awareness while in flight (Ellis, 1993).

Figure 4 Flight Director

There is a frame of reference that pilots use to understand devices such as the flight director. There is a representation of the real world embedded in the flight director's graphics that allows pilots to orient themselves on a coordinate system to understand the aircraft's position and adjust it given the amount of error in positioning. Wickens, Liang, Prevett, and Olmos (1996) conducted an experiment that tested map rotation, dimensionality, and traveling direction. As they explain; "the effects of frame of reference or map rotation are noticeable when the ego-referenced, rotating map display facilitated performance while flight path tracking." This technique eliminated the need for mental rotation creating an advantage observed between map rotation and direction of flight. In the current system for uplink clearance communication there is a similar situation when pilots cognitively process the auditory and occasionally visual (text) information from ATC onto the frame of reference for the aircraft's path, usually projected on the ND. Currently, most ATC clearances are not lengthy or complex, allowing pilots to easily retain clearance information and mentally project it onto the aircraft path for evaluation and further response to ATC. The NextGen plan will implement 4D trajectory clearances posing a much higher level of demand on pilot cognitive processes. This may result in performance failures in the form of inaccurate decisions to accept clearances that are erroneous or reject valid clearances due to misinterpretation. Moreover, if the clearance must be manually entered into the FMS for execution, data entry errors are likely to rise in proportion to the complexity of the clearance. Graphics have the potential of translating the information (NAS language) from ATC to a pictorial representation on the ND, eliminating the need for pilots to retain uplink clearance information in verbal working memory and translate it to a mental spatial representation for evaluation.

The NASA graphics developed for future aircraft does not consider the minimal capabilities of the current commercial aircraft. The FAA is interested in developing human factors guidelines for the display of graphics on the flight deck, taking into to consideration the near and mid-term NAS in which most aircraft are not equipped with significant graphic capability. However, many commercial aircraft have the ND.

Currently the ND depicts the graphical representation of the planned aircraft route including all waypoints as well as the dynamically changing position of the aircraft on that route. Essentially this display is a map that the pilot uses to mentally monitor the aircraft's trajectory. Figure 5 is an image of a Boeing 737 ND; top left shows the distance to next waypoint and true air speed, middle top shows the heading in degrees, and top right shows the Zulu time and the ground speed. The magenta line indicates the current route and the stars along the route are the location of the waypoints with their respective names. The range of the map is depicted by the middle line from the triangle at the bottom to the heading box at the top; the numerical value equals half of the range (in this case 80.0).

Figure 5 Boeing Style Navigation Display. 2004. Retrieved May 20th, 2013, from: http://secure.simmarket.com/ernie-alston-integrated-simavionics-group-1-(isg1).phtml

The current research study was developed within the context of a larger FAA research project with the primary purpose of creating human factors guidelines based on human-in-the-loop simulation. The focus was a comparison of TEXT versus hybrid GRAPHICS +TEXT formats on human performance. In 1992 Hahn and Hansman used the ND to test how automation affects situational awareness while communicating clearances. The relationship was tested by implementing automated entry of a clearance into the FMS and testing the pilot's ability to recognize an erroneous clearance. The research resulted in the findings that the automation of the FMS relieved cognitive load with the purpose of allowing pilots to focus on the implications of a clearance message. Hahn tested clearance communication in three modes: auditory, textual, and graphic. The results revealed that textual and graphic communication mode had similar subjective scores; subjects perceived each to have their own advantages and disadvantages. Graphic delivery had a decision-making advantage, whereas textual delivery advantage was the compact format. Graphic delivery of clearances enabled superior performance over verbal and text delivery modes. Subjects were able to detect a greater percentage of erroneous routing clearances in less time than with the graphic mode. Hahn and Hansman (1992) recommended combining presentation of textual & graphic delivery; however they mentioned that because the graphical information was dispersed in the different flight deck displays it was difficult to understand the clearance message. Although textual delivery had the concise format advantage it lacked decision-aiding advantages. The current study investigates hybrid approaches as suggested by Hahn and Hansman. In this study the graphic clearance information is presented on the ND and a new altitude situation display. The textual information is either next to the ND or integrated into the graphics on the ND.

III. GOALS AND OBJECTIVES

Research Goal

The goal of this research was to assess the speed and accuracy with which pilots can interpret DataComm ATC clearances as a function of the text based, graphical or combined format used to display the messages.

Objectives

The first objective of this research was to determine any differences in pilot performance when interpreting uplink messages of varying lengths and content sent as clearances via DataComm displays using text-only versus a hybrid of text and graphic communication formats. The second objective was to determine whether different graphical formats affect the interpretability of uplink messages of varying lengths and content.

The third objective was to identify any trends in performance or subjective pilot opinion concerning the relationships between the number of elements contained within a single clearance and the speed or accuracy of message interpretation. For the purposes of this analysis, a message element was defined as variable within a clearance. For example, the clearance, "CLIMB TO [level]" has one element, while “PROCEED TO [location] VIA [location], [location]” contains three elements.

IV. METHOD

PREDICTIONS

Specific observations need to be performed to formulate conclusions that will address the objectives. An essential prediction was formulated based on the references discussed on the background sections about human performance while performing clearance communication.

- 1st Essential prediction: Based on the reference analysis on text and graphics for DataComm the prediction is that; Clearance interpretation will occur more quickly and accurately while using graphics and text rather than text only as a communication format when transmitting clearances with more than one element.
- 2nd Prediction: Clearance interpretation will occur more quickly and accurately while using a graphic altitude situation display rather than using an ND with altitude in text on the ND and in the text clearance.
- 3rd Prediction: Clearance interpretation will occur more quickly and accurately while using a hybrid of text imbedded in graphics rather than a hybrid of text and graphics. This prediction is based on the concept that the pilot will not be required to direct attention to the graphics and text separately.

- 4th Prediction: Clearance interpretation time and accuracy will be the same for both correctly accepting a clearance and correctly rejecting a clearance.

Experimental Design

The experiment utilized a between-subjects design. There was one independent variable; communication format. There was also a control variable; number of elements in a clearance. The control variable allows the comparison of clearances between different communication formats by grouping clearances containing the same number of elements. Clearances with a higher number of elements can be considered to be more complex; however, it is not a direct measure of each clearances cognitive complexity.

There were five levels of communication formats described below. The dependent variables were response time to interpret a clearance and percent correct answers. All pilots were trained according to the format they were tested on before the experiment. Pilots participated in four to five practice scenario trials to learn how to operate the software. The duration of the experiment varied depended upon the number of clearances used per format; times ranged on average from 30 to 90 minutes. The order in which the pilots advanced through the scenarios was randomized. The randomization or the scenario order was computer generated by the testing software. Testing sites included Wright State University and Cessna Aircraft Corporation in Wichita, KS.

Independent Variable Levels

1. Baseline text only (Text)

This format showed the text clearance to the right of the navigation display. Forty clearances were created from the SC214 message set. These clearances ranged from 1 to 6 and one 9 element clearance. The display used to test this format had three main areas; flight plan box, text clearance box, and ND box. The ND box showed waypoints, current route, range of view, heading, distance to next waypoint, name of next waypoint, and current altitude. See Figure 6.

Figure 6 Text format Sample Scenario

2. Graphics + text separated (G + T)

The clearances used in this format are a duplicate from the text format minus 1 clearance (Maintain [Level, dropped from the original 40 because it was no longer being used in the SC-214 data set). Thirty-nine clearances were tested in this format. The text clearance was located to the right of the ND and the graphics were implemented into the ND. The graphics were used in the ND at the location that they should be executed along the route. See Figure 7 for an example of a "Proceed Direct to POSITION" clearance. This clearance required the use of the dashed line. There were slight changes in color in the flight plan box (green to yellow) and clearance's text color (yellow to green) from the Text format.

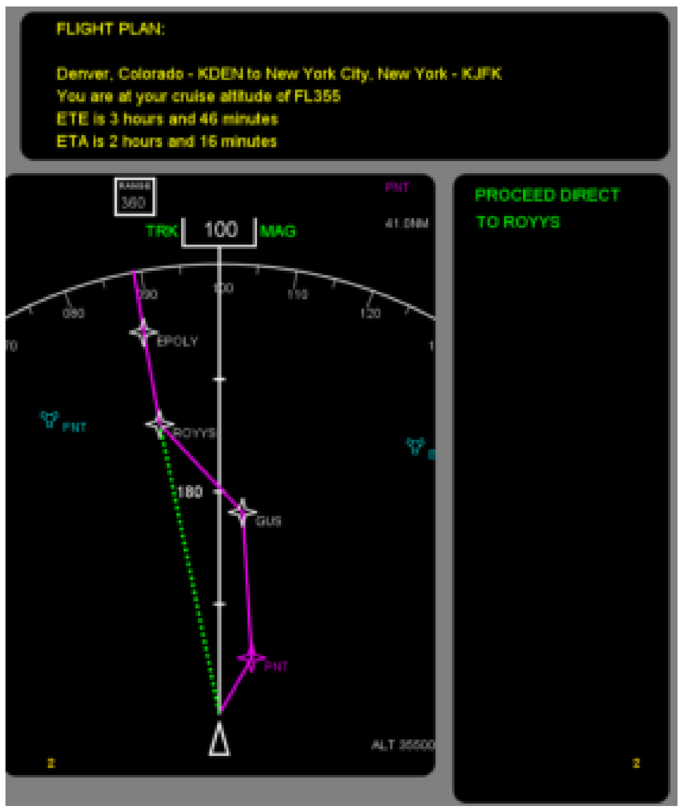


Figure 7 G+T format Sample Scenario

3. Graphics + text separated with updated UM wording (G + T + upd UM)

This format only included clearances that were updated from the original 40 clearance set used in the text format. Updates were made by the SC214 committee and two experts from the airspace community. Table 5 lists 19 clearances that were updated from the original 40. All original clearances are listed in Table 4. This format followed the same format as G+T. Figure 8 illustrates an example of a complex clearance. This clearance message had 5 elements. The flight plan wording was reduced slightly under this format to lessen the amount of words used to describe the plan.

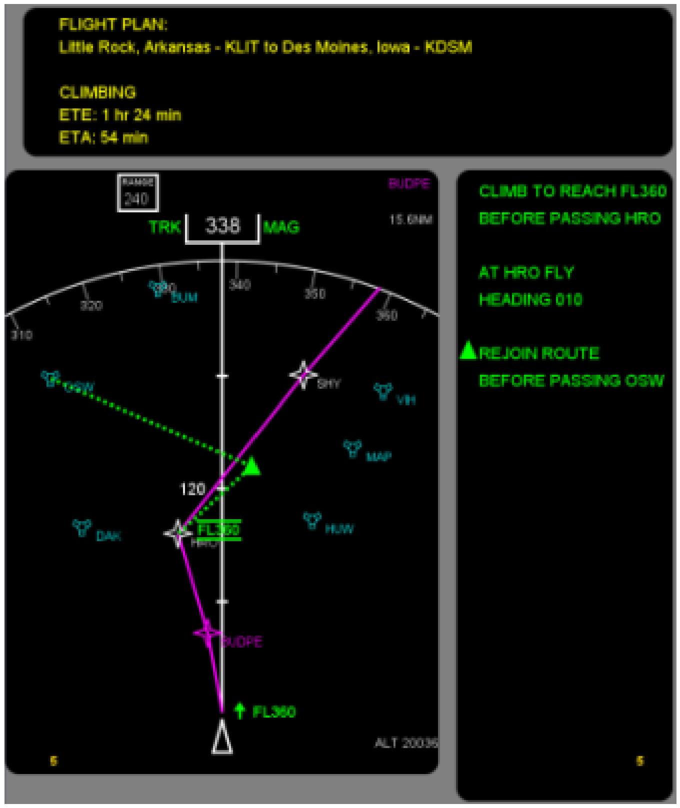


Figure 8 G+T+updUM format Sample Scenario

4. Graphics + text separated with altitude shown graphically – Altitude Situation Display (ASD) (G +T + ASD)

In this format all altitude related clearances (after updates from Committee and experts) were tested. Twenty-two clearances were tested; all clearances had at least one altitude related element. The text was displayed to the right of the ND, the graphics were used in the ND, and the altitude situation display (ASD) was displayed directly beneath the ND. Format G+T+ASD added yet another window to the display (a separated graphic). The ASD was used to provide a different way for the pilot to track current and future altitude of the aircraft as well as changes indicated by clearances (see Figure 9).

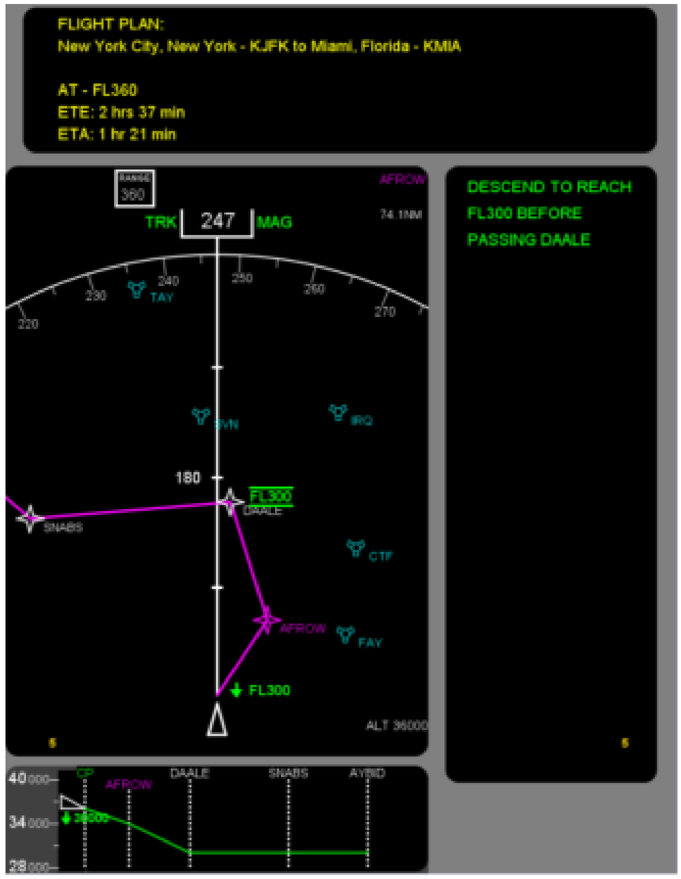


Figure 9 G+T+ASD format Sample Scenario

5. Graphics with text imbedded into the image (G + IT + ASD)

   A smaller set of clearances were tested in this format. Eleven concatenated clearances were used; no one-element clearances were tested in this format. Nine of the eleven clearances included altitude so that the ASD may be referred to. The UM text that previously was displayed on the right was imbedded with the graphics into the ND. The wordings from the clearances were shortened in an attempt to reduce clutter. Format G+IT+ASD eliminated the use of the clearance text box. In Figure 10 a high complexity re-route clearance is shown. This format focused on implementing text along with graphics in the ND.

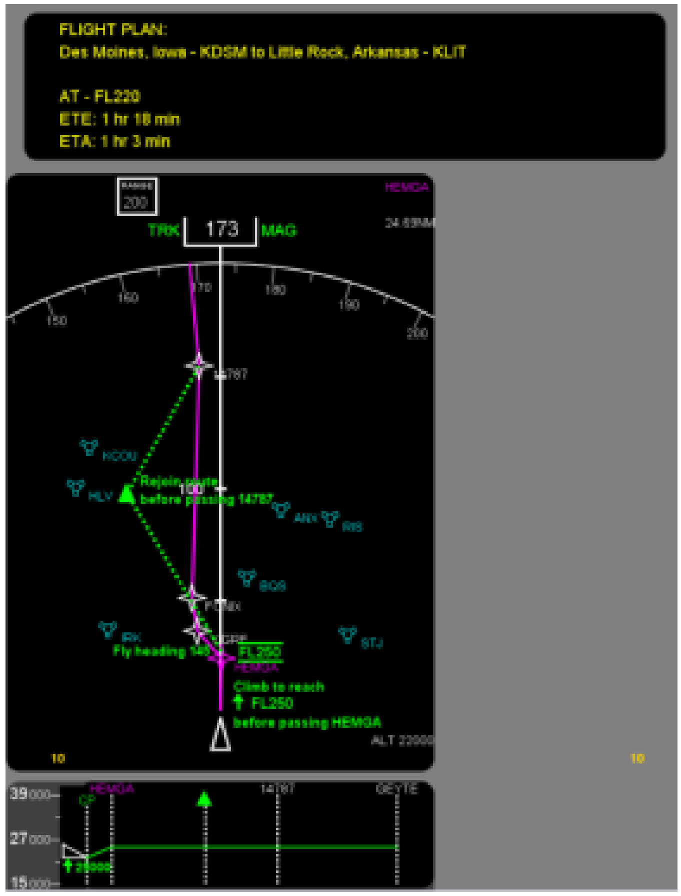


Figure 10 G+IT+ASD format Sample Scenario

DEPENDENT VARIABLES

Pilot performance was measured using two dependent variables: response time and correct response. Each UM clearance was replicated 4 times. The same clearance was tested in 4 different scenarios; 2 in which the subject should have rejected the clearance message and, 2 in which the subject should have accepted the clearance message. The response time reflected the time it took pilots to make a decision as to whether to accept or reject the clearance message. Correct response referred to correctly accepting a clearance that should have been accepted and correctly rejecting a clearance that should have been rejected.

SUBJECTS

Pilots were recruited from the Dayton region and from Cessna Aircraft Corp. in Wichita Kansas. Pilots were screened for a minimum of 100 flight hours. A total of 66 individuals were tested across the various formats. Not all participants saw all formats. Each subject participated in two formats maximum. All subjects were given the same instructions and information about the operation and purpose of the experiment. The average age of the pilots was 43.4 years. The mean average of flight hours for pilots was 5926 hours. 97.5% of the subjects were instrument rated. 90% of the pilots were male. The pilots were recruited from different backgrounds in aviation; 75% had commercial background, 15% had general/private aviation background, and 10% had military background.

APPARATUS

HARDWARE

The experiment was controlled via a Hewlett Packard (HP) laptop; model – Elitebook 8560p, and a portable 18 inch LCD monitor model – L1940T. Connected to the HP laptop was an external 19-key keypad (model – FC K19U) data entry device. In Figures 11, 12, and 13 each piece of hardware is presented. The LCD screen presented the subjects with the graphic and textual information while the keypad controlled the steps to accomplish the task.


Figure 11 participant's view of the simulator


Figure 12 experimenter's view of the simulator

Figure 13 external keypad

SOFTWARE

The software was custom designed and developed using JAVA language and run in the NetBeans IDE. The software controlled the presentation of all display formats, timing, and data collection. A description of the specific software tool was created;

DataComm Message Assessment Tool (DC-MAT) is described in a subsequent section below.

TEXT AND GRAPHIC SYMBOLS

Aviation like any other discipline has its own terminology and language shortcuts, therefore the graphics involved must be designed to suit the natural language of pilots. Clearances are based on voice messages. Each clearance message is composed of technical language and variable elements. For example: "At FL350 Proceed Direct to SILOW". The underlined parts of this clearance are the messages variables, which are referred to in this report as elements. Elements are the key to translating messages into graphic clearances. There are different types of UM in the clearances used in this research: altitude, direction, and position. In the previous example FL350 is an altitude element and SILOW is a position element. "Fly heading 270" is a directional clearance and 270 is the respective directional element. Graphics are based on the language of the UM, for example "Proceed Direct to" or "Fly Heading" are constants in the clearance message. The constant technical language can be represented with constant set of graphics to graphically depict the clearance. Based on the SC214 set, a protocol was developed to present both text only and hybrid (text + graphic) clearances for pilots to evaluate the interpretability of these communication formats.

The graphics designed for the experiment are basic geometric figures and lines. The following Figures described the graphics symbols in correlation to the respective UM used and their meaning. Each graphic was used across all tested formats. Not all the graphics were used in every scenario, only when needed to satisfy the UM clearance displayed.

1. **Triangle:** Indicated when to begin the execution of a clearance at a specific location (position)(Figure 14).

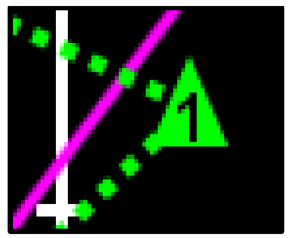


Figure 14 Triangle

2. **Green dotted line & magenta line:** The line depicted an alternate path given by a re-route clearance and was represented by the green dotted line. The magenta solid line represented the current and original aircraft path. (Figure 15).

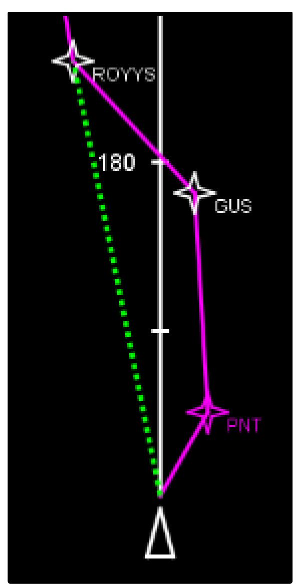


Figure 15 Green Dotted Line and Magenta Line

3. **Green caret line:** Illustrated the specific heading direction of a clearance. It did not show an alternative re-route path (Figure 16).

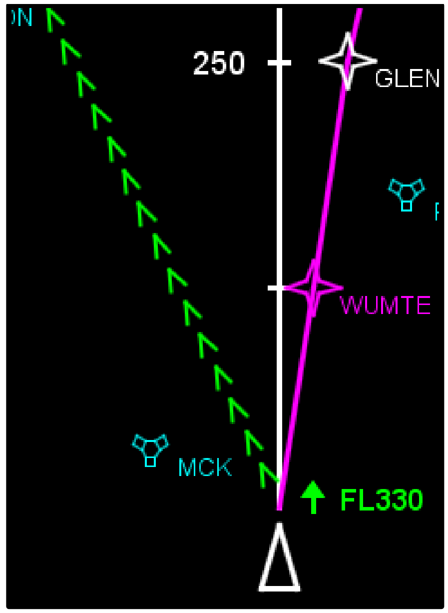


Figure 16 Heading Caret Line

4. **Text next to current position:** Indicated the immediate execution of a clearance, see Figure 17. The current position is specified by the white triangle.

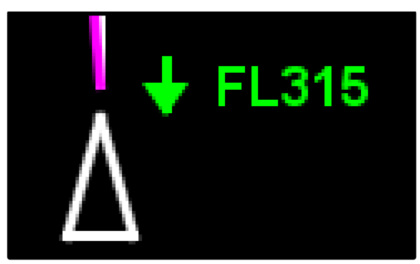


Figure 17 Graphic + Text Next to Current Location

5. **Altitude next to triangle**: Showed the altitude related to the clearance for the specific location (Figure 18).

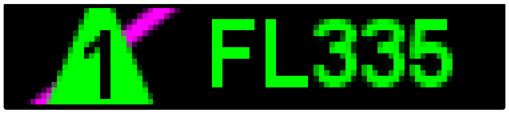


Figure 18 Graphics + Text altitude element

6. **Arrow next to text**: Illustrated the direction (climb/descend) of the altitude change related to the clearance (Figure 19).

Figure 19 Arrow - Altitude Change and Direction

7. **Line below the text:** The line indicated to reach and stay at or above the altitude indicated by the clearance (Figure 20). **Line above the text:** indicated to stay at or below the altitude indicated by the clearance.

Figure 20 Solid Line Below the Altitude

8. **Line above and below:** It showed to reach and stay at the altitude indicated by the clearance (Figure 21).

Figure 21 Solid Lines Above and Below the Altitude

9. **Numbers inside a triangle**: These numbers indicated chronological order of clearances when two or more concatenated clearances were used in a scenario as a sequence (Figure 22).

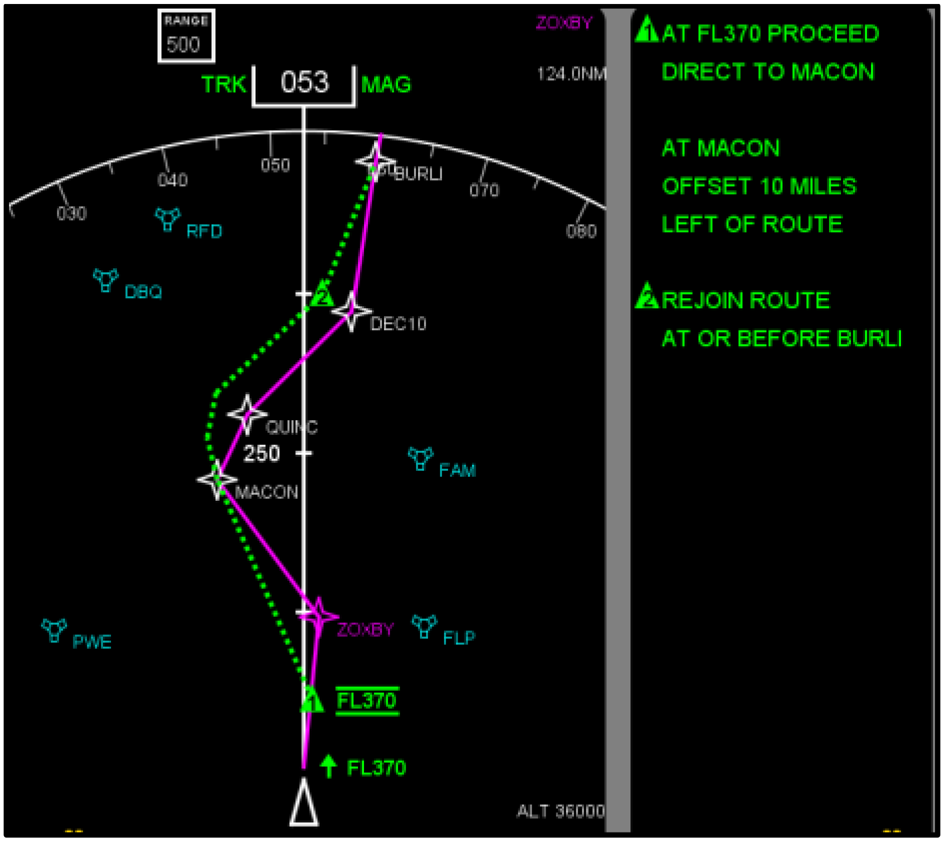


Figure 22 Scenario with Two Concatenated Clearances

10. **ASD –current state.** This display showed the current altitude path of the flight with the radar fixes that need to be crossed along the route. The magenta line indicated the current vertical path of the aircraft, see Figure 23.

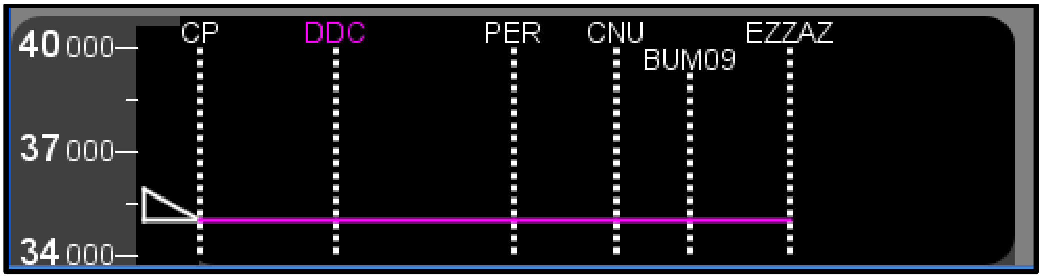


Figure 23 ASD Showing the Current Vertical Route

11. **ASD –clearance state.** This display showed the alternative altitude path as indicated by the ATC UM clearance, including the updated radar fixes that are to be crossed along the route. The green line represented the proposed vertical path by the clearance message (Figure 24). During the experiment the subject had the ability to toggle between the current state and clearance state.
    a. **Arrow next to number**: This illustrated the direction (climb/descend) of the altitude change related to the clearance.
    b. **Number next to arrow**: Indicated the target altitude.

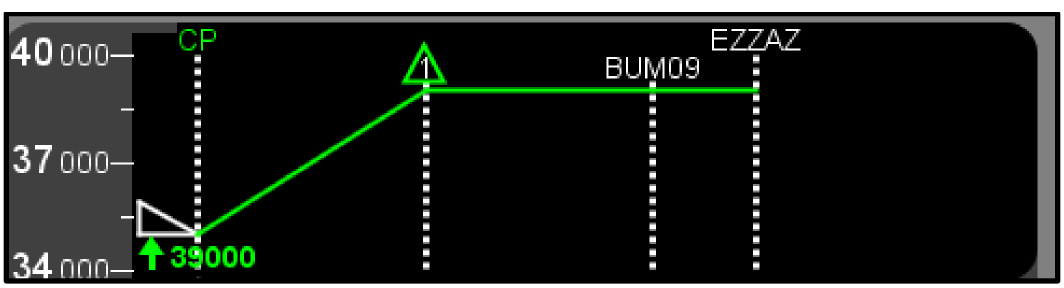


Figure 24 ASD Displaying the Clearance Route

CLEARANCES

The special committee – 214 (SC-214) of RTCA is formed from members of the aviation community with extensive experience in commercial flying, the NAS and ATC at the domestic and international level. These experts are responsible for creating the message set that air traffic controllers will have at their disposal to communicate with pilots through uplink messages (UMs). For the purposes of this study 40 UMs were created ranging from 1 to 9 elements in each clearance. Table 5 shows the baseline set of 40 clearances used for the text only and G+T communication formats.

Table 4 Clearances Tested Text vs. G+T

Clearance			Format / # subjects	
SC-214 Clearance	**UM Number**	**Element**	**Text / 10**	**G+T / 8**
MAINTAIN [level]	UM19	One	*	
CLIMB TO [level]	UM20	One	*	*
DESCEND TO [level]	UM23	One	*	*
FLY HEADING [degrees]	UM190	One	*	*
PROCEED DIRECT TO [position]	UM74	One	*	*
EXPECT DIRECT TO [position]	UM87	One	*	*
REJOIN ROUTE AT OR BEFORE [position]	UM68	One	*	*
EXPECT BACK ON ROUTE BY [position]	UM70	One	*	*
AT [position] CLIMB TO [level]	UM22	Two	*	*
AT [position] DESCEND TO [level]	UM25	Two	*	*
AT [level] PROCEED DIRECT TO [position]	UM78	Two	*	*
AT [level] EXPECT DIRECT TO [position]	UM90	Two	*	*
AT [position] FLY HEADING [DEGREES]	UM97	Two	*	*
AT [position] PROCEED DIRECT TO [position]	UM77	Two	*	*
AT [position] EXPECT DIRECT TO [position]	UM88	Two	*	*
TURN [direction] [degrees] DEGREES	UM215	Two	*	*
CLEARED TO [position] VIA [route clearance enhanced]	UM79	Two	*	*
AT [position] CLEARED [route clearance]	UM83	Two	*	*
CROSS [position] AT [level]	UM46	Two	*	*
CROSS [position] AT OR ABOVE [level]	UM47	Two	*	*
CROSS [position] AT AND MAINTAIN [level]	UM49	Two	*	*
CLIMB TO REACH [level] AT OR BEFORE [position]	UM27	Two	*	*
DESCEND TO REACH [level] AT OR BEFORE [position]	UM29	Two	*	*
DESCEND TO [level]. FLY HEADING [degrees]	UM23, UM190	Two	*	*
CLIMB TO [level]. FLY HEADING [degrees]	UM20, UM190	Two	*	*
AT [position] OFFSET [specified distance] [direction] OF ROUTE	UM65	Three	*	*
AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM339	Three	*	*
DESCEND TO [level]. TURN [direction] HEADING [degrees]	UM23, UM94	Three	*	*
PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]	UM74, UM97	Three	*	*
CLIMB TO [level]. FLY HEADING [degrees]. PROCEED DIRECT TO [postion]	UM20, UM190, UM74	Three	*	*
CLIMB TO REACH [level] AT OR BEFORE [position]. AT [position] PROCEED DIRECT TO [position].	UM27, UM77	Four	*	*
TURN [direction] [degrees] DEGREES. CLIMB TO [level]. REJOIN ROUTE AT OR BEFORE [position]	UM215, UM20, UM68	Four	*	*
FLY HEADING [degrees]. CLIMB TO [level]. TURN [direction] [degrees] DEGREES.	UM190, UM20, UM215	Four	*	*
AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE AT OR BEFORE [position].	UM65, UM68	Four	*	*
AT [position] PROCEED DIRECT TO [position]. AT [position] DESCEND TO [level]. Fly HEADING [degrees]	UM77, UM25, UM190	Five	*	*
CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM79, UM339	Five	*	*
CLIMB TO REACH [level] AT OR BEFORE [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE AT BEFORE [position]	UM27, UM97, UM68	Five	*	*

SC-214 Clearance	UM Number	Element	Text / 10	G+T / 8
AT [level] PROCEED DIRECT TO [position]. AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE AT OR BEFORE [position].	UM78, UM65, UM68	Six	*	*
DESCEND TO [level]. AT [level] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE AT OR BEFORE [position].	UM23, UM78, UM97, UM68	Six	*	*
AT [position] CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM339, UM339, UM339	Nine	*	*

Throughout the duration of the study the RTCA committee updated the message set; changing and eliminating clearance elements. As the message set evolved the initial 40 clearances were updated along with it. In addition to the changes made by to the SC-214, two subject matter experts evaluated the initial 40 clearance set and reorganized the order of the elements in some clearances. Table 5 shows the clearances that were updated from the initial 40 clearance set in italics as well as all remaining clearances tested in the hybrid formats.

Table 5 Updated Clearances + Clearances Used in Hybrids

Clearance (*italics = updated UMs)*			Format / # subjects		
SC-214 Clearance	**UM Number**	**Element**	**G+T+updUM/20**	**G+T+ASD/20**	**G+IT+ASD/8**
CLIMB TO [level]	UM20	One		*	
DESCEND TO [level]	UM23	One		*	
REJOIN ROUTE BEFORE PASSING [position]	UM68	One	*		
AFTER PASSING [POSITION] CLIMB TO [level]	UM22	Two	*	*	
AFTER PASSING [position] DESCEND TO [level]	UM25	Two	*	*	
AT [level] PROCEED DIRECT TO [position]	UM78	Two		*	*
AT [level] EXPECT DIRECT TO [position]	UM90	Two		*	*
CLEARED TO [position] VIA [route clearance enhanced]	UM79	Two			*
CROSS [position] AT [level]	UM46	Two		*	
CROSS [position] AT OR ABOVE [level]	UM47	Two		*	
CROSS [position] AT AND MAINTAIN [level]	UM49	Two		*	
CLIMB TO REACH [level] BEFORE PASSING [position]	UM27	Two	*	*	*
DESCEND TO REACH [level] BEFORE PASSING [position]	UM29	Two	*	*	*
FLY HEADING [degrees]. DESCEND TO [level]	UM190, UM23	Two	*	*	
FLY HEADING [degrees]. CLIMB TO [level]	UM190, UM20, UM215	Two	*	*	
TURN [direction] HEADING [degrees]. DESCEND TO [level]	UM94, UM23	Three	*	*	
FLY HEADING [degrees]. CLIMB TO [level]. AT [level] PROCEED DIRECT TO [position]	UM190, UM20, UM78	Three	*	*	
CLIMB TO REACH [level] BEFORE PASSING [position]. AT [position] PROCEED DIRECT TO [position].	UM27, UM77	Four	*	*	*
TURN [direction] [degrees] DEGREES CLIMB TO [level]. REJOIN ROUTE BEFORE PASSING [posiion]	UM215, UM20, UM68	Four	*	*	

SC-214 Clearance	UM Number	Element	G+T+updUM/20	G+T+ASD/20	G+IT+ASD/8
FLY HEADING [degrees]. CLIMB TO [level]. AT [level] PROCEED DIRECT TO [position]	UM190, UM20, UM78	Four	*	*	
AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position].	UM65, UM68	Four	*		*
AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]. DESCEND TO [level]	UM77, UM97, UM23	Five	*	*	*
CLEARED TO [position] VIA [position, position, position]	UM79	Five	*		
CLIMB TO REACH [level] BEFORE PASSING [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE BEFORE PASSING [position]	UM27, UM97, UM68	Five	*	*	*
AT [level] PROCEED DIRECT TO [position]. AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position].	UM78, UM65, UM68	Six	*	*	*
DESCEND TO [level]. AT [level] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE BEFORE PASSING [position].	UM23, UM78, UM97, UM68	Six	*	*	*
AT [position] CLEARED TO [position] VIA [position, position, position, position, position]	UM339	Nine	*		

DataComm Message Assessment Tool (DC-MAT)

A method was designed to evaluate the interpretation of clearances by measuring pilot's time to respond to a clearance and response percent corrects. The evaluation method was designed by the WSU research team and named DataComm Message Assessment Tool (DC-MAT). It uses a binary judgment task to collect performance data on clearance interpretation time and percent corrects, and to obtain feedback from pilots concerning the interpretability of clearances. The goal was to provide a methodology for independently evaluate DataComm. The method focused on uplink clearances that affect an aircraft's current or future trajectory (e.g. speed, heading, altitude, and route). This methodology was not designed to evaluate instructions that do not affect the route of flight (e.g. transfer of communications, contact/monitor, and report requests). The flight plan information was located on the top box; this information was given to the pilot to give situational awareness about the scenario. The left box was the emulated ND from a Boeing 737-400; the amount of information in this display was enough for subjects to make a decision. Depending upon the format used to test the pilots graphics would be used in this area of the display. The text box on the right displayed the textual clearance information. See Figure 25 for an example of the situational awareness given to the pilot and see Figure 26 for an example of clearance information to the pilot.

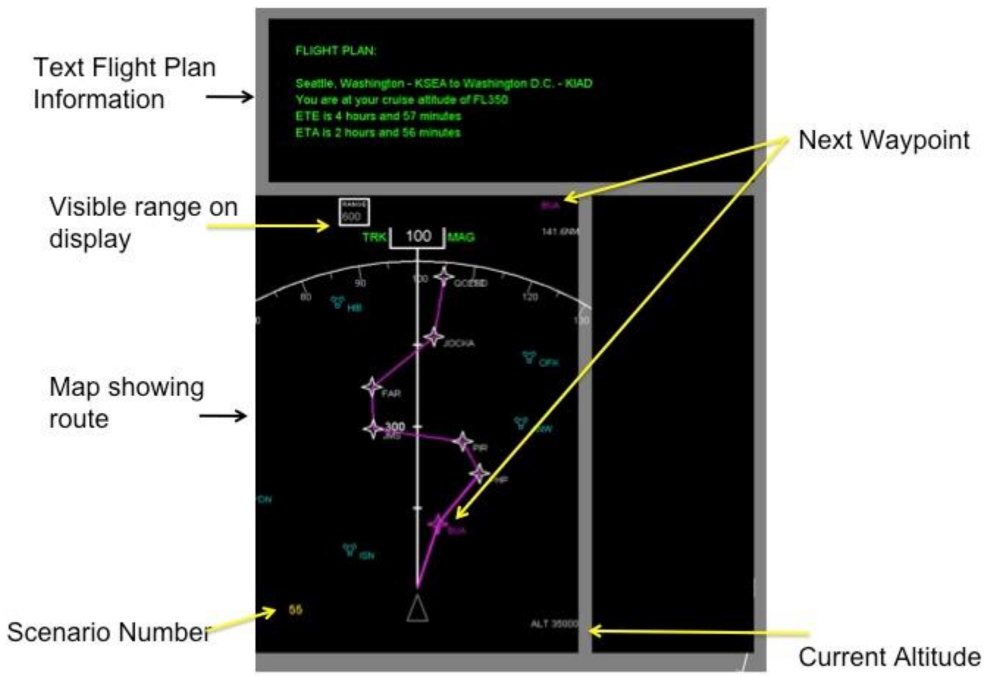


Figure 25 Situational Awareness Information

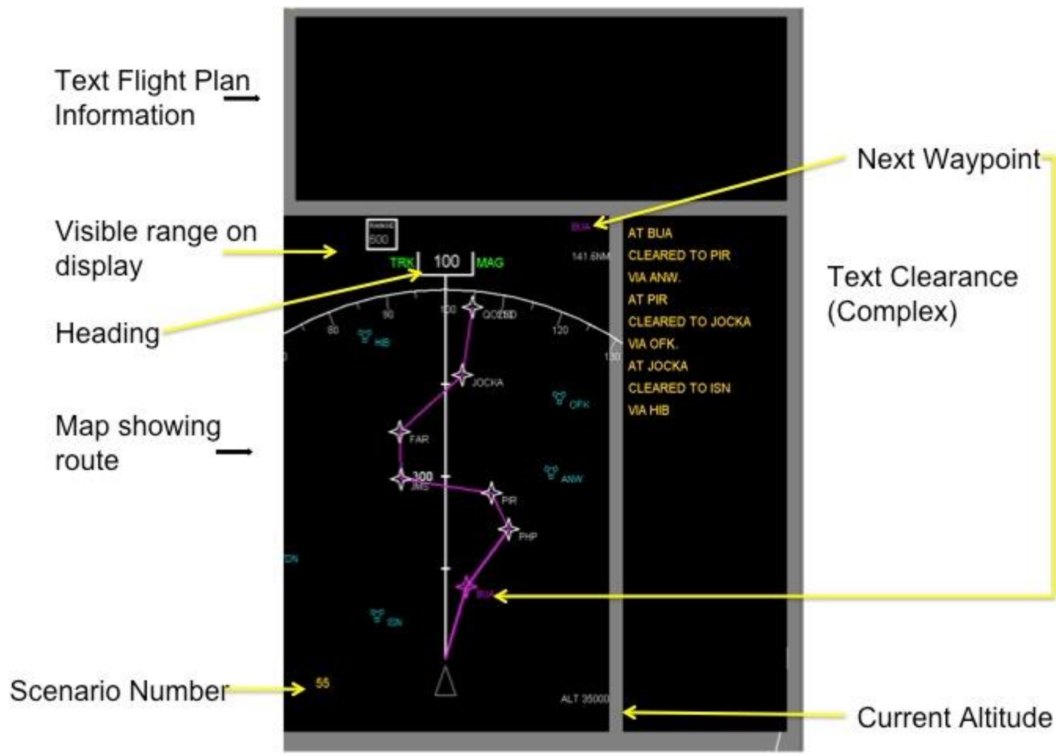


Figure 26 Clearance information

DC-MAT collected data within a text file and included the following: Number of elements in a clearance, clearance number, clearance complexity rating, stimulus number, random sequence, if text flight plan was recalled, answers (correct/incorrect), time to study flight plan before requesting clearance, time to make a judgment, and total time.

Experimental Procedure

The participant sat in front of the screen with a small keyboard input device. The enter key was used to indicate they were ready to evaluate the current flight situation. When the enter button was pressed again, a timer was started. The participant was asked to review the flight plan and map until they understood the current situation. Once they became familiar with the situation, they pressed the enter button again and the flight situation study time was recorded. At the same time, the clearance was displayed, the flight plan text was removed, and the response timer was started. Pilots also had the option of displaying the flight plan again by pressing the backspace (BS) button. Under graphic conditions the clearance was displayed by symbols that appeared on the map (navigation display) representing the written clearance in graphical form. After reviewing the clearance, the participant either accepted or rejected the clearance by pressing 1 or 3 respectively on the external keypad. The judgment was based on the information provided to the participant through the flight plan and navigation display. Additionally for formats that used the ASD (G+T+ASD and G+IT+ASD) the pilot had the opportunity to toggle back and forward between the altitude situation display (ASD) current state and clearance state by pressing the "0" number key.

The protocol calls for removing the textual flight plan information (but not the graphical route display) after it is understood (when the participant is ready to read the clearance). The pilots were allowed to bring the flight plan back up with a button press with the intention of providing textual reference of their route which is available in current aircraft via maps or other options. Those scenarios in which the participant brought back the flight plan were noted in the data file.

The participant was instructed to accept the clearance if it directly matched the flight plan they had studied or if the clearance called for a deviation from the flight plan but leads them to the same destination or future waypoint on the original plan. The participant rejected the clearance if it does not match the flight plan or sends them on a path that does not lead to their destination. In addition the subject rejected the clearance due to excessive additional distance flown (even if directed back to destination), inappropriate altitude for phase of flight, and altitude mismatch. For example the clearance may have required flying to a waypoint already passed, or to a waypoint off the flight plan and in the in the wrong direction. If the pilot felt that a scenario and clearance were confusing they were asked to note the scenario number, but to move forward and respond to the clearance. Participants were asked to respond as they would during actual flight by accurately evaluating the clearance in a timely fashion followed by rapidly indicating an intent to comply (accept) or their concern about the acceptability or validity of the clearance by responding with a rejected clearance.

Upon completion of all trials the scenarios that the participant indicated were confusing were reviewed directly with the participant. Qualitative data was collected this way which provided a better understanding of their perceptions and difficulties related to scenarios or clearances.

V. RESULTS

Data Overview – Description and Manipulation

The DC-MAT created data output files for every subject in a .txt file. The raw data were imported into excel files and analyzed in Statistical Analysis Software (SAS) version 9.2 on a Windows 7 operating system. The procedure PROC MIXED was used for analysis to deal with unequal N across conditions. The statistical analysis performed on the data consisted of an analysis of variance (ANOVA) for a mixed factor design with two variables: format and response. Format, with five levels, refers to the presentation technique, TEXT, G+T, etc. Response refers to whether the response should be to accept the clearance or to reject the clearance. The use of response as an IV in the analysis provided the ability to analyze if the pilots correctly accepted or rejected clearances based on format type. A significant criterion of $p \leq 0.05$ was used to evaluate all main effects and interactions. Post-hoc Tukey-Kramer tests were performed for significant main effects. These were assessed using a Least Squares Means test with a Tukey-Kramer adjustment for multiple comparisons. The pilot performance data analyzed included the subjects' response time and the percent correct answers. An ANOVA was performed to find any significant difference in the data; if the ANOVA showed any significant difference then a simple effects test and a Tukey-Kramer were performed to find any further significant differences in the data.

The response time variable had outliers identified in the data. The criteria used to identify these outliers were the following; some pilots had a tendency to talk about the scenario with the experimenter during a trial affecting response time. This behavior caused the data to have noticeable longer response times. These instances were noted during the experiment and the outliers were removed. The number of outliers were a small fraction of the entire dataset (less than 7%). When applying Proc Mixed the Restricted Maximum Likelihood (REML) method was used for data estimation. Data were evaluated for normality using the Shapiro-Wilks test and were found to be normally distributed.

ONE ELEMENT CLEARANCES

There were 8 different one element UM clearances. Table 6 indicates which UMs were used for each format and the number of subjects tested in each format. (Note one element clearances were not tested in the format G+IT+ASD).

Table 6 One Element Tested Clearances

Clearance		format Number of subjects tested			
SC-214 UM Text	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**	**G+T+ASD 20**
MAINTAIN [level]	UM19	*			
CLIMB TO [level]	UM20	*	*		*
DESCEND TO [level]	UM23	*	*		*
FLY HEADING [degrees]	UM190	*	*		
PROCEED DIRECT TO [position]	UM74	*	*		
EXPECT DIRECT TO [position]	UM87	*	*		
REJOIN ROUTE AT OR BEFORE [position]	UM68	*	*	*	
EXPECT BACK ON ROUTE BY [position]	UM70	*	*		

Mean Response time

The ANOVA summary table is provided in Table 7.

Table 7 ANOVA Summary for One Element Mean Response Time

Source	*df*	Type III SS	Mean Square	F Value	p-value
response	1	416.6642	416.664178	12.55	0.0008*
format	3	884.7466	294.915536	6.38	0.0009*
format*response	3	392.5077	130.835885	3.94	0.0129*

The two main effects (response and format) were statistically significant as well as the interaction (format*response). The mean response time as a function of response is illustrated in Figure 27; subjects correctly rejected clearances in less time (x = 6.25 sec) than accepting them (x = 7.94 sec). The mean response time as a function of format is shown in Figure 28. The letters indicate the significant differences between formats. The adjusted Tukey-Kramer analysis for format is presented in Table 8. The results indicate that response time was lower with the G+T compared to G+T+udpUM and G+T+ASD. However, there was no significant difference in response time between Text and G+T for the one element clearance. The significant slice interaction of format*response are noted in Figure 29 by "*" next to the mean response value; Table 9 represented the simple effect F-test for significant differences in response within each format. The analysis indicated that for formats G+T+updUM ($p = 0.0107$) and G+T+ASD ($p = 0.0001$) mean response times were faster when pilots correctly rejected a clearance compared to when they correctly accepted a clearance. The magnitude of the difference in RT for accept and reject for these two formats is less than 1 second.

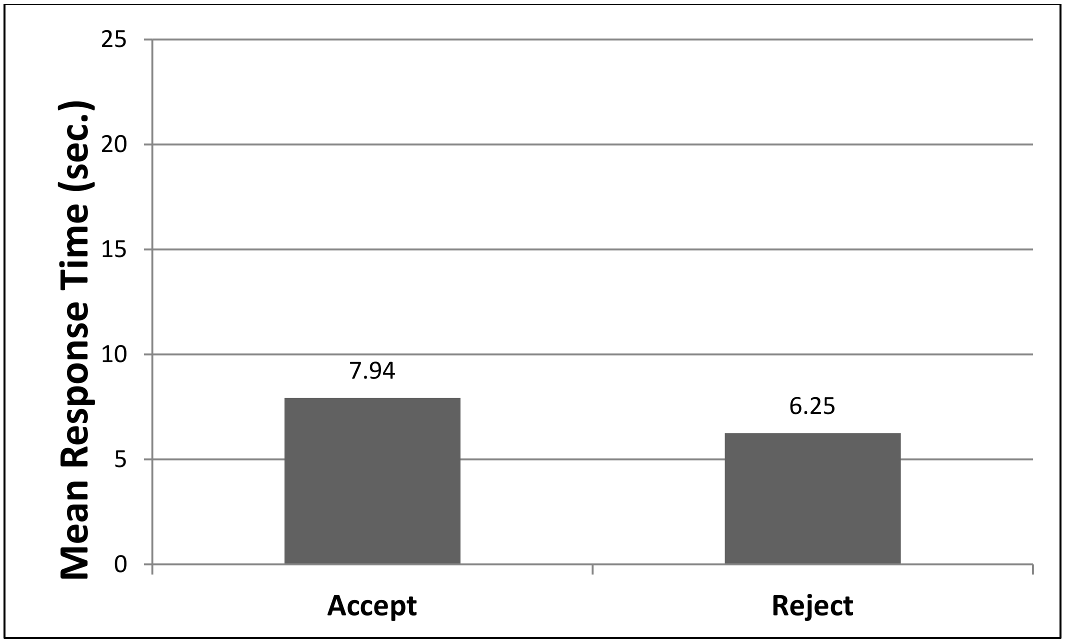


Figure 27 One Element Mean Response Time as a Function of response

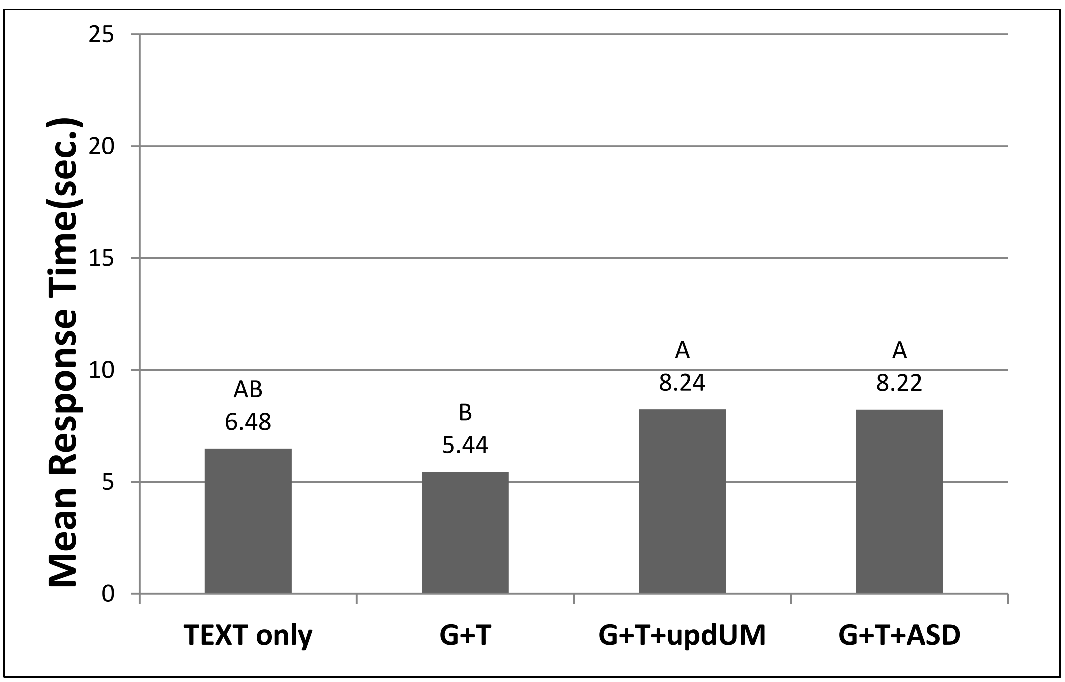


Figure 28 One Element Mean Response Time as a Function of format

Table 8 One Element Comparison of Response Time for format main Effect

format	format	Estimate	Standard Error	df	tValue	Pr>|t|	Adj	Adj P
TEXT only	G+T	1.0296	0.8109	54	1.27	0.2097	Tukey-Kramer	0.586
TEXT only	G+T+updUM	-1.5963	0.802	54	-1.99	0.0516	Tukey-Kramer	0.2043
TEXT only	G+T+ASD	-1.7103	0.7232	54	-2.37	0.0217	Tukey-Kramer	0.0963
G+T	G+T+updUM	-2.6259	0.8528	54	-3.08	0.0033	Tukey-Kramer	.0167*
G+T	G+T+ASD	-2.7398	0.779	54	-3.52	0.0009	Tukey-Kramer	.0048*
G+T+updUM	G+T+ASD	-0.1139	0.7698	54	-0.15	0.8829	Tukey-Kramer	0.9988

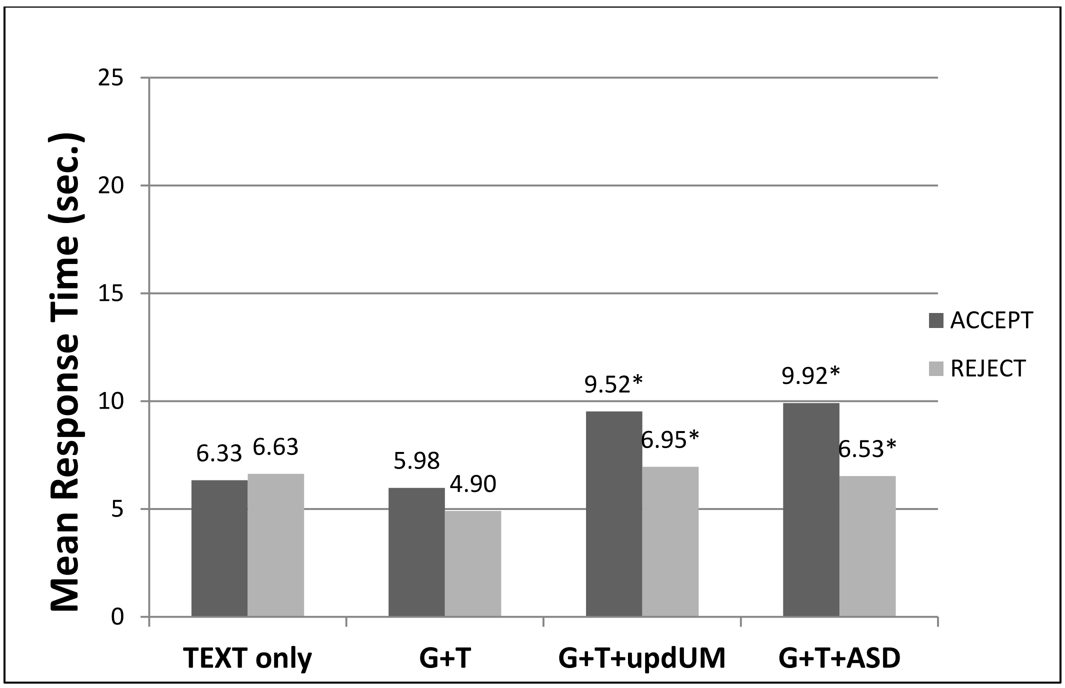


Figure 29 One Element Mean Response Time as a Function of format*response

Table 9 One Element format*response Interaction Sliced by format for Response Time

format	DF	Sum of Squares	Mean Square	F-value	p-value
TEXT only	1	7.032373	7.032373	0.19	0.6751
G+T	1	61.644918	61.644918	1.46	0.2319
G+T+updUM	1	125.565636	125.565636	6.98	0.0107*
G+T+ASD	1	437.83322	437.83322	23.98	0.0001*

Mean Percent Correct

Table 10 presented the ANOVA summary for the dependent variable percent correct. The ANOVA indicated that there are no statistically significant differences in performance.

Table 10 One Element ANOVA Summary for Percent Correct

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
format	3	54	0.59	0.6237
response	1	54	2.08	0.1548
format*response	3	54	0.57	0.6353

TWO ELEMENT CLEARANCES

Seventeen different clearances were used to test two element clearances, summarized in Table 11.

Table 11 Two Element Clearance Breakdown by format

Clearance		**format Number of subjects tested**				
SC-214 UM Text	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**	**G+T+ASD 20**	**G+IT+ASD 8**
AT [position] CLIMB TO [level]	UM22	*	*	*	*	
AT [position] DESCEND TO [level]	UM25	*	*	*	*	
AT [level] PROCEED DIRECT TO [position]	UM78	*	*		*	*
AT [level] EXPECT DIRECT TO [position]	UM90	*	*		*	*
AT [position] FLY HEADING [DEGREES]	UM97	*	*			
AT [position] PROCEED DIRECT TO [position]	UM77	*	*			
AT [position] EXPECT DIRECT TO [position]	UM88	*	*			
TURN [direction] [degrees] DEGREES	UM215	*	*			
CLEARED TO [position] VIA [route clearance enhanced]	UM79	*	*			*
AT [position] CLEARED [route clearance]	UM83	*	*			
CROSS [position] AT [level]	UM46	*	*		*	

SC-214 UM Text	UM Number	Text 10	G+T 8	G+T+updUM 20	G+T+ASD 20	G+IT+ASD 8
CROSS [position] ATOR ABOVE [level]	UM47	*	*		*	
CROSS [position] AT AND MAINTAIN [level]	UM49	*	*		*	
CLIMB TO REACH [level] AT OR BEFORE [position]	UM27	*	*	*	*	*
DESCEND TO REACH [level] AT OR BEFORE [position]	UM29	*	*	*	*	*
DESCEND TO [level]. FLY HEADING [degrees]	UM23, UM190	*	*	*	*	
CLIMB TO [level]. FLY HEADING [degrees]	UM20, UM190	*	*	*	*	

Mean Response Time

The two element clearances were tested under all five Formats. The ANOVA summary is presented in Table 12.

Table 12 Two Element ANOVA Summary for Mean Response Time

Source	DF	Type III SS	Mean Square	F Value	p-value
response	1	1347.16724	1347.167237	25.89	<.0001*
format	4	7691.76117	1922.940291	12.18	<.0001*
format*response	4	906.02776	226.50694	4.35	0.0044*

The two main effects response (p = <0.0001) and format (p = <0.0001) and the interaction format*response (p = 0.0044) were significant. The two element clearance mean response times are shown in Figure 30. Clearances were rejected (x = 8.02 sec) significantly faster than when they were accepted (x = 9.82 sec). The main effect of format is illustrated in Figure 31; the significant differences are shown by letters. The results of the post-hoc test comparing formats are presented in Table 13. Mean response time for TEXT, G+T, G+T+updUM were not significantly different from each other but all three are significantly different from both G+T+ASD and G+IT+ASD; subjects on average took less time to respond to TEXT , G+T, G+T+updUM compared to G+T+ASD and G+IT+ASD. The fastest response time overall was G+T.

The mean response times for the interaction between format and response are illustrated in Figure 32. The simple-effect F-test is shown in Table 14. There was a significant difference in response time between clearances correctly accepted or rejected for the two formats G+T+ASD and G+IT+ASD. In both cases rejecting a clearance was faster than accepting a clearance, but the magnitude of the difference was slightly larger for G+IT+ASD by 1.04 seconds.

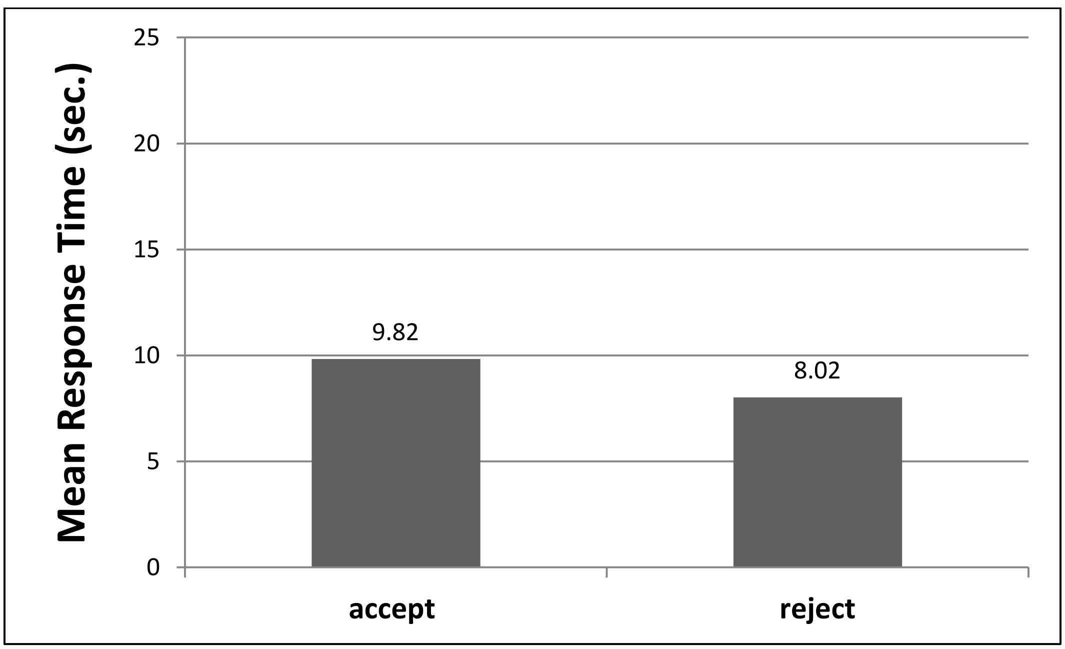


Figure 30 Two Element Mean Response Time as a Function of response

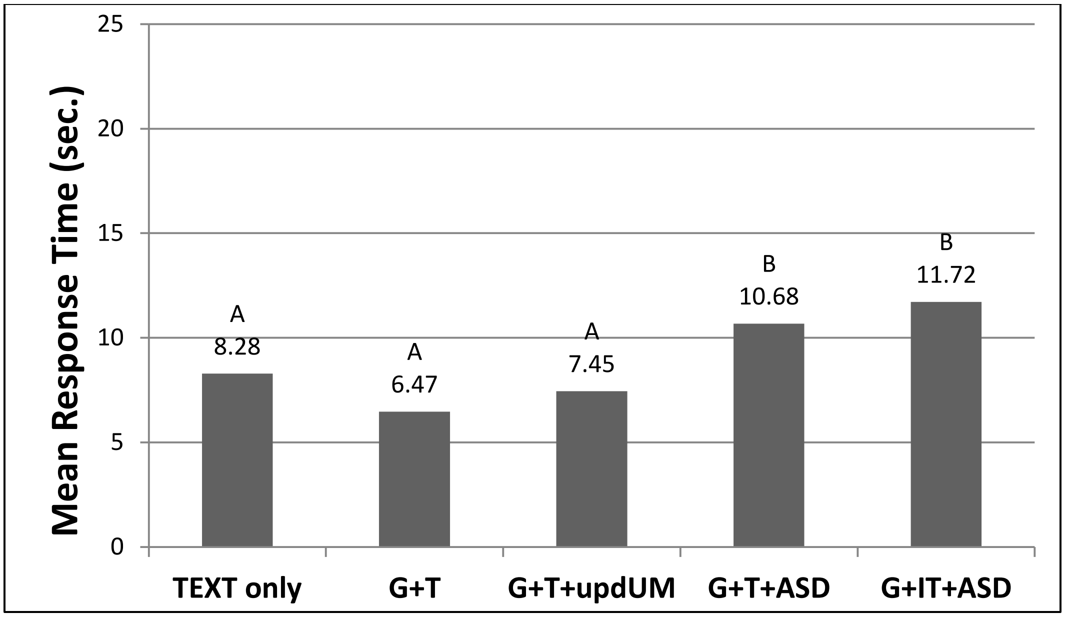


Figure 31 Two Element Mean Response Time as a Function of format

Table 13 Two Element Comparison of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	1.8184	0.9271	61	1.96	0.0544	Tukey-Kramer	0.2971
TEXT only	**G+T+upd UM**	0.8423	0.7798	61	1.08	0.2843	Tukey-Kramer	0.816
TEXT only	**G+T+ASD**	-2.3727	0.764	61	-3.11	0.0029	Tukey-Kramer	.0232*
TEXT only	**G+IT+AS D**	-3.3584	1.0141	61	-3.31	0.0016	Tukey-Kramer	.0131*
G+T	**G+T+upd UM**	-0.976	0.839	61	-1.16	0.2492	Tukey-Kramer	0.772
G+T	**G+T+ASD**	-4.191	0.8244	61	-5.08	<.0001	Tukey-Kramer	.0001*
G+T	**G+IT+AS D**	-5.1768	1.0603	61	-4.88	<.0001	Tukey-Kramer	.0001*
G+T+upd UM	**G+T+ASD**	-3.215	0.6544	61	-4.91	<.0001	Tukey-Kramer	.0001*
G+T+upd UM	**G+IT+AS D**	-4.2008	0.9343	61	-4.5	<.0001	Tukey-Kramer	.0003*
G+T+ASD	**G+IT+AS D**	-0.9858	0.9211	61	-1.07	0.2888	Tukey-Kramer	0.821

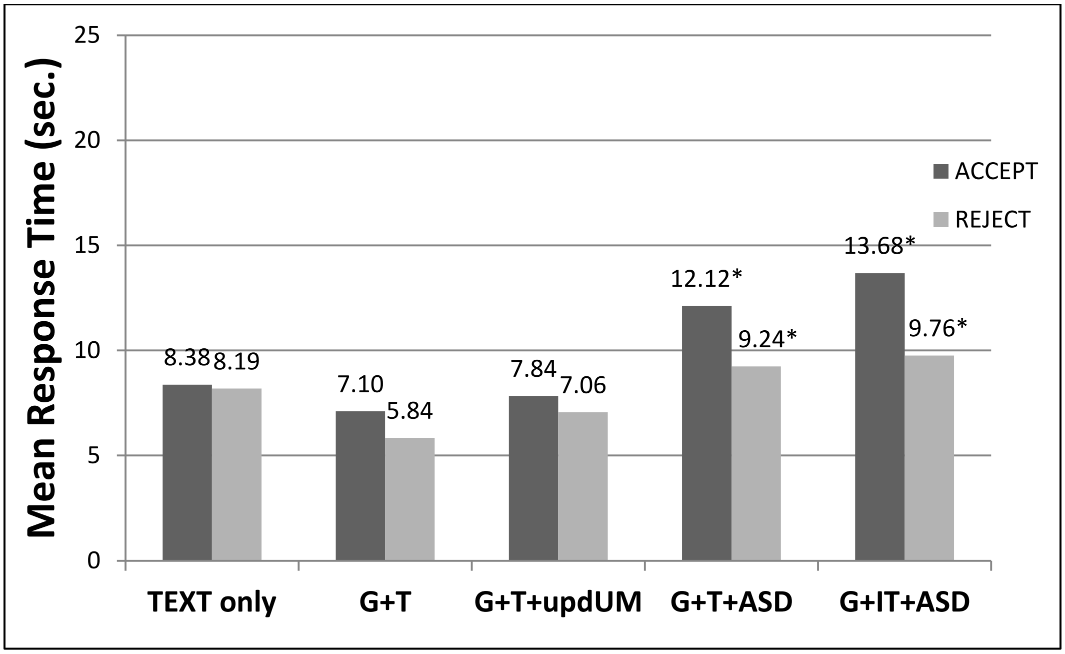


Figure 32 Two Element Mean Response Time as a Function of format*response

Table 14 Two Element format*response Interaction Sliced by format for Response Time

format*response Effect Sliced by format for response_TIME					
format	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
TEXT only	1	6.071769	6.071769	0.24	0.726
G+T	1	204.072118	204.072118	2.99	0.0920
G+T+updUM	1	70.713337	70.713337	2.77	0.0960
G+T+ASD	1	1717.03957	1717.039573	67.22	<.0001*
G+IT+ASD	1	445.626894	445.626894	17.45	<.0001*

Mean Percent Correct

Table 15 presents the ANOVA summary for mean percent correct.

Table 15 Two Element ANOVA Summary for Percent Correct

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
response	1	61	4.84	0.0317*
format	4	61	2.91	0.0286*
format*response	4	61	0.82	0.5153

The two main effects response (p = 0.0317) and format (p = 0.0286) were significant. The two-way interaction showed no statistical significance. When subjects responded to two element clearances, they did so with higher accuracy when correctly rejecting (90.06%) compared to correctly accepting (85.38%) as illustrated in Figure 33. The main effect of communication format is shown in Figure 34. The Tukey-Kramer analysis for the significant differences between communication formats is shown in Table 16. Because of the conservative nature of the test, the post-hoc comparisons showed no differences. However, we can conclude based on the ANOVA main effect that the lowest mean percent correct (G+T+ASD X=82.50) is significantly different than the highest percent correct (G+T, X=90.44).

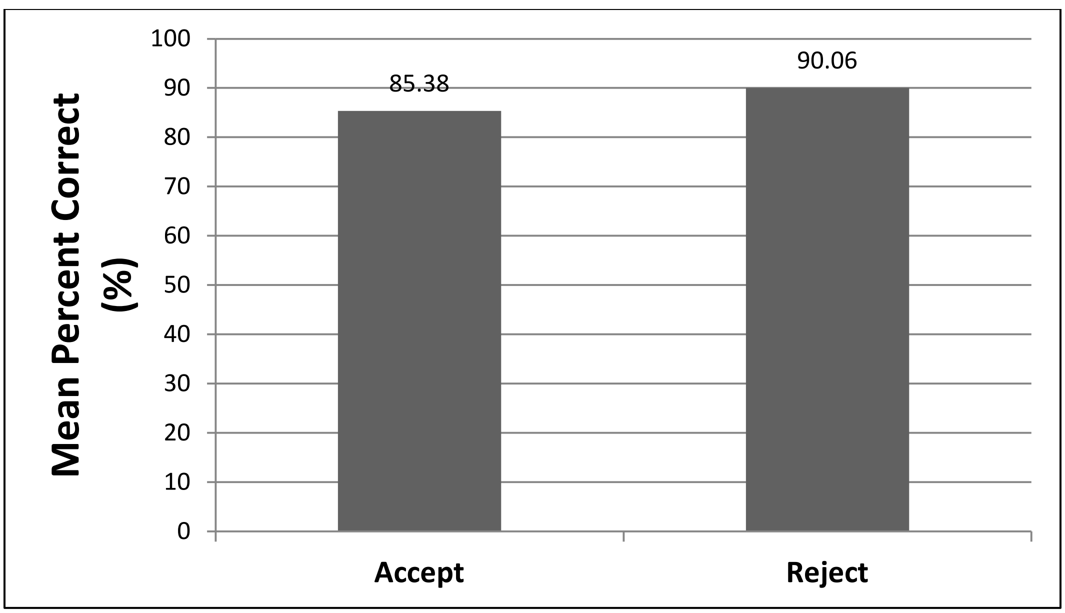


Figure 33 Two Element Mean Percent Correct as a Function of response

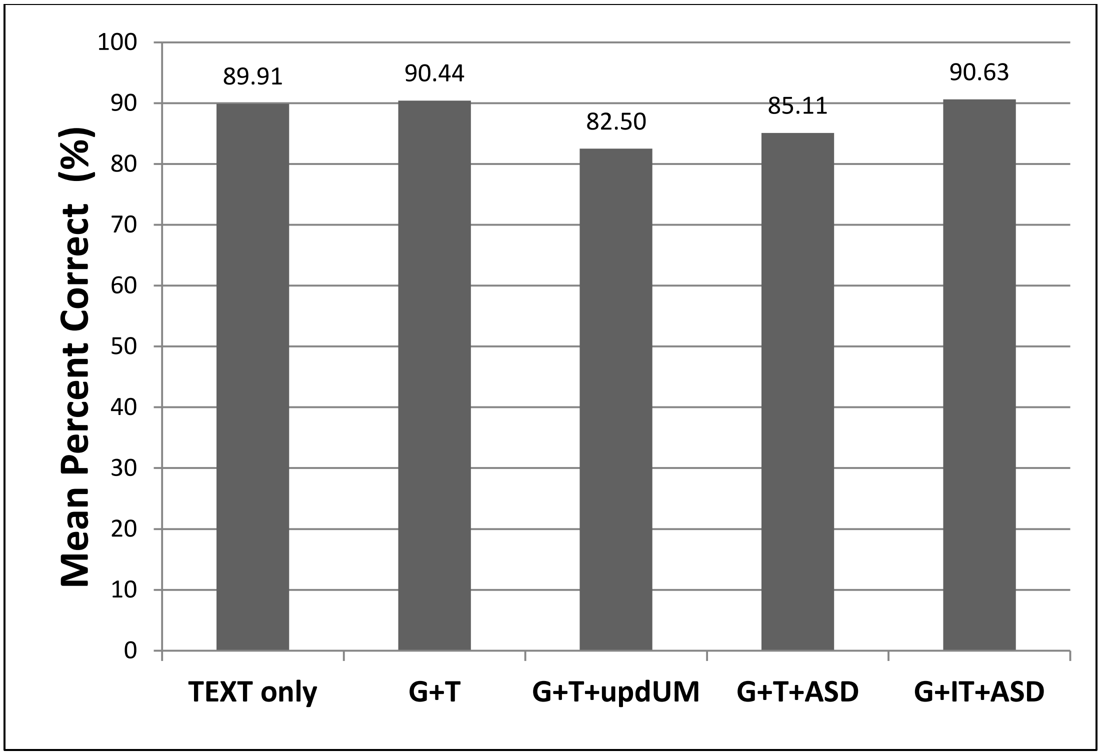


Figure 34 Two Element Mean Percent Correct as a Function of format

Table 16 Two Elements Comparisons of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	-0.5285	3.7667	61	-0.14	0.8889	Tukey-Kramer	0.9999
TEXT only	**G+T+updUM**	7.4127	3.0755	61	2.41	0.019	Tukey-Kramer	0.1264
TEXT only	**G+T+ASD**	4.7991	3.0755	61	1.56	0.1238	Tukey-Kramer	0.5281
TEXT only	**G+IT+ASD**	-0.7123	3.7667	61	-0.19	0.8506	Tukey-Kramer	0.9997
G+T	**G+T+updUM**	7.9412	3.3219	61	2.39	0.0199	Tukey-Kramer	0.1318
G+T	**G+T+ASD**	5.3275	3.3219	61	1.6	0.1139	Tukey-Kramer	0.5008
G+T	**G+IT+ASD**	-0.1838	3.9704	61	-0.05	0.9632	Tukey-Kramer	1
G+T+updUM	**G+T+ASD**	-2.6136	2.5111	61	-1.04	0.3021	Tukey-Kramer	0.8354
G+T+updUM	**G+IT+ASD**	-8.125	3.3219	61	-2.45	0.0173	Tukey-Kramer	0.1171
G+T+ASD	**G+IT+ASD**	-5.5114	3.3219	61	-1.66	0.1022	Tukey-Kramer	0.4665

THREE ELEMENT CLEARANCES

Table 17 lists the five different concatenated UMs used to evaluate the three element clearances across four formats.

Table 17 Three Element Clearance Breakdown by format

Clearance		format Number of subjects tested			
Message Verbiage	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**	**G+T+ASD 20**
AT [position] OFFSET [specified distance] [direction] OF ROUTE	UM65	*	*		
AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM339	*	*		
DESCEND TO [level]. TURN [direction] HEADING [degrees]	UM23, UM94	*	*	*	*
PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]	UM74, UM97	*	*		
CLIMB TO [level]. FLY HEADING [degrees]. PROCEED DIRECT TO [position]	UM20, UM190, UM74	*	*	*	*

Mean Response Time

Table 18 presents the ANOVA summary for the three element clearances for mean response time.

Table 18 Three Element ANOVA Summary for Response Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
response	1	769.498996	769.4989964	23.34	<0.0001*
format	3	1569.48272	523.160905	8.14	0.0004*
format*response	3	187.407737	62.4692456	1.89	0.141

The ANOVA for response time indicated that both main effects response (p = <0.0001) and format (p = 0.0004) resulted in significant differences. The interaction of format*response was not statistically significant. The response main effect is illustrated in Figure35. Pilots correctly rejected (x =8.14) clearances significantly faster than correctly accepting (x = 10.31) them. Figure 36 illustrated the main effect of format. The adjusted Tukey-Kramer analysis is presented in Table 19. G+T, with the fastest mean response time, was significantly different than Text and G+T+ASD but not significantly different than G+T+updUM. Text and G+T+ASD were not significantly different from one another. The significant differences between formats are denoted by different letters and illustrated in Figure 36.

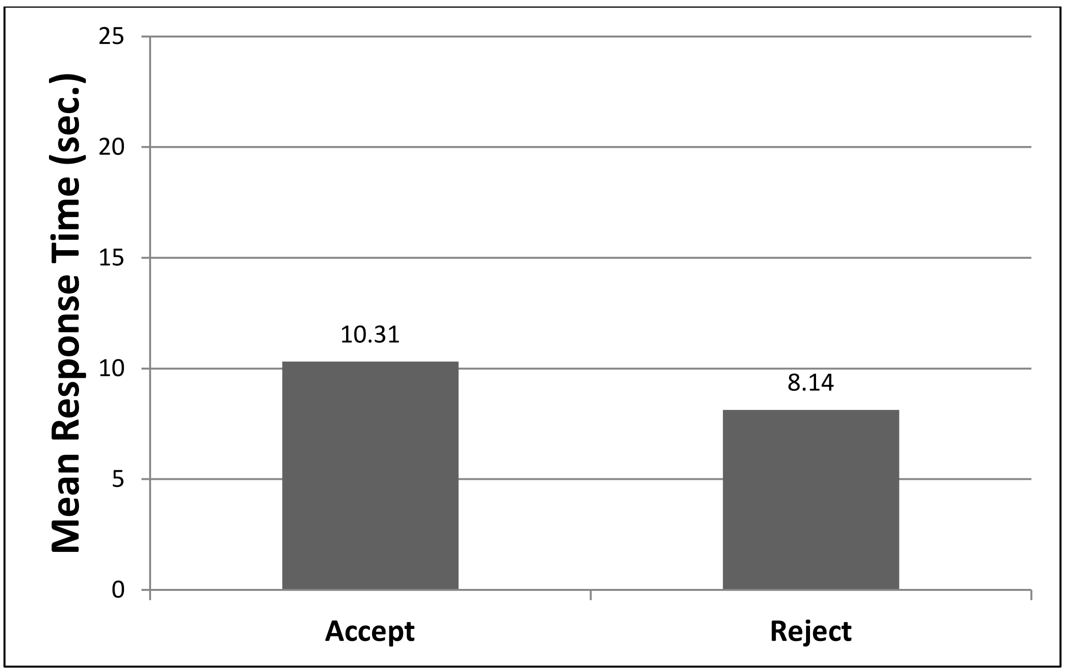


Figure 35 Three Element Mean Response Time as a Function of response

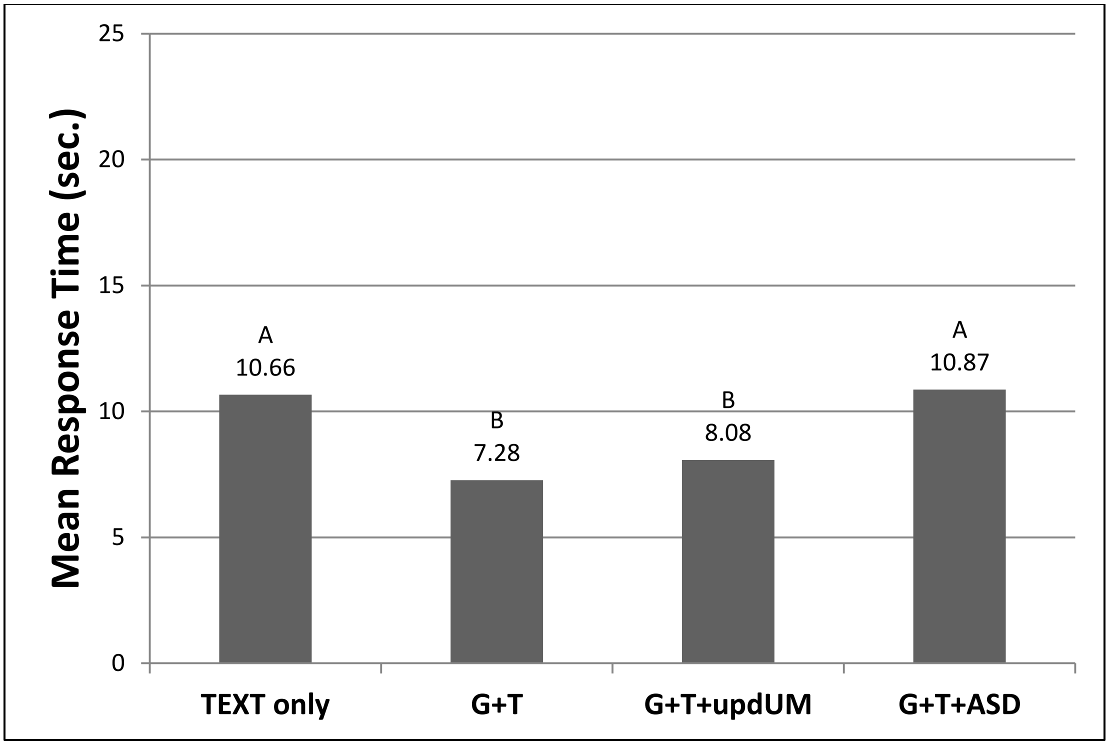


Figure 36 Three Element Mean Response Time as a Function of format

Table 19 Three Element Comparison of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	3.4551	1.0778	54	3.21	0.0023	Tukey-Kramer	.0118*
TEXT only	**G+T+updUM**	2.6249	0.9291	54	2.83	0.0066	Tukey-Kramer	.0325*
TEXT only	**G+T+ASD**	-0.1779	0.9305	54	-0.19	0.8491	Tukey-Kramer	0.9975
G+T	**G+T+updUM**	-0.8302	1.0008	54	-0.83	0.4104	Tukey-Kramer	0.8402
G+T	**G+T+ASD**	-3.633	1.0021	54	-3.63	0.0006	Tukey-Kramer	.0035*
G+T+updUM	**G+T+ASD**	-2.8028	0.8402	54	-3.34	0.0015	Tukey-Kramer	.0082*

Mean Percent Correct

Table 20 summarized the ANOVA for Mean Percent Correct for three element clearances which were tested under four formats.

Table 20 Three Element ANOVA Summary for Percent Correct

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
response	1	54	0.73	0.397
format	3	54	5.36	0.0027*
format*response	3	54	2.78	0.0499*

The ANOVA for percent correct indicated that the main effect of format (p = 0.0027) and the interaction format*response (p = 0.0499) were statistically significant, see Table 21. The four communication formats were illustrated in Figure 37. G+T and G+T+updUM resulted higher percent correct than TEXT and G+T+ASD but were not significantly different from one another. The results of the Tukey-Kramer test are shown in Table 22 and the letter on the Figure 37 indicated the significant differences between formats.

The results for the Simple-Effects F-test indicated that subjects had higher percentage of correct responses when correctly rejected a clearance under the format of G+T+ASD, see Figure 38. Table 22 contains the analysis results for this test.

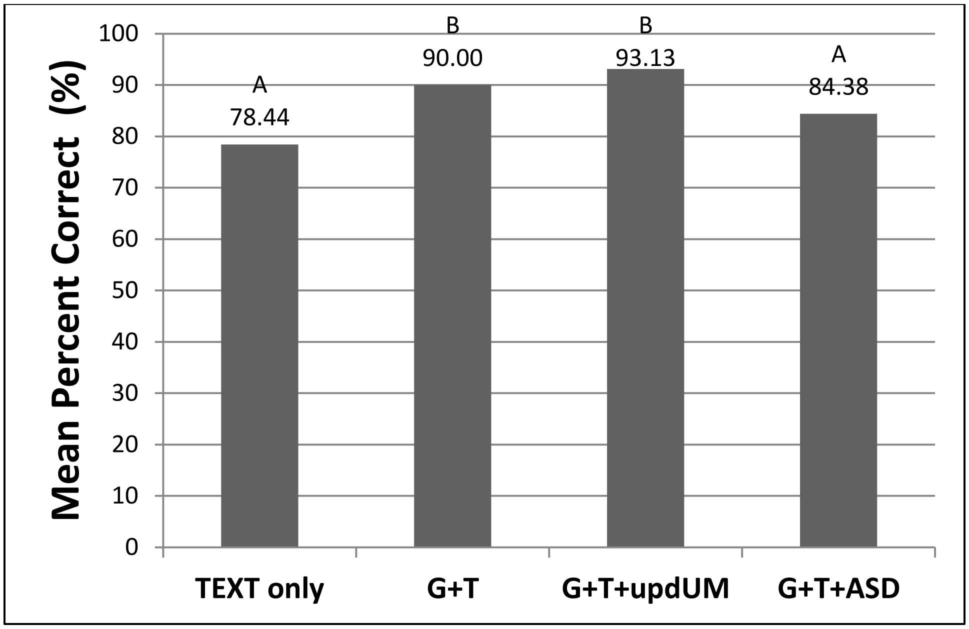


Figure 37 Three Element Mean Percent Correct as a Function of format

Table 21 Three Element Comparison of Percent Correct for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	3.4551	1.0778	54	3.21	0.0023	Tukey-Kramer	.0118*
TEXT only	**G+T+updUM**	2.6249	0.9291	54	2.83	0.0066	Tukey-Kramer	.0325*
TEXT only	**G+T+ASD**	-0.1779	0.9305	54	-0.19	0.8491	Tukey-Kramer	0.9975
G+T	**G+T+updUM**	-0.8302	1.0008	54	-0.83	0.4104	Tukey-Kramer	0.8402
G+T	**G+T+ASD**	-3.633	1.0021	54	-3.63	0.0006	Tukey-Kramer	.0035*
G+T+updUM	**G+T+ASD**	-2.8028	0.8402	54	-3.34	0.0015	Tukey-Kramer	.0082*

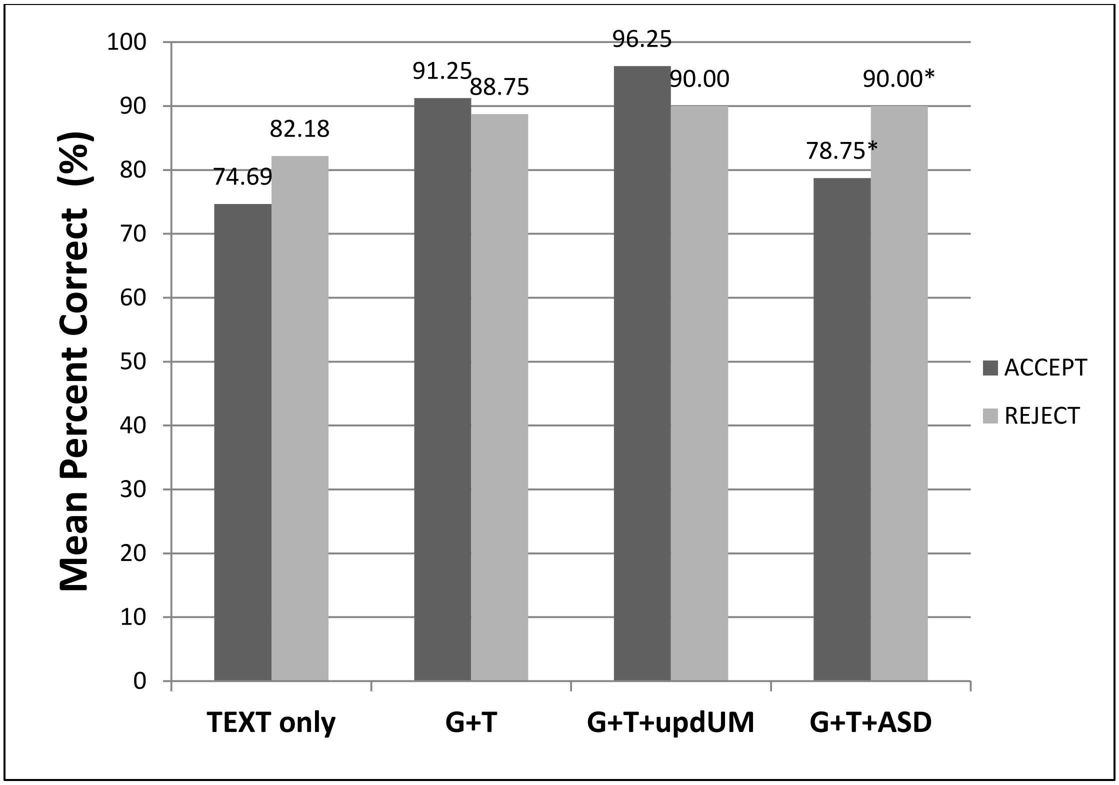


Figure 38 Three Element Mean Percent Correct as a Function of format*response

Table 22 Three Element format*response Interaction Sliced by format for Percent Correct

Effect	format	DF	Den DF	F Value	Pr > F
format*response	TEXT only	1	54	1.33	0.2536
format*response	G+T	1	54	0.12	0.7318
format*response	G+T+updUM	1	54	1.85	0.1789
format*response	G+T+ASD	1	54	6.01	0.0175*

FOUR ELEMENT CLEARANCES

Table 23 lists the four concatenated UMs evaluated as four element clearances under all five format conditions.

Table 23 Four Element Clearance Breakdown by format

Clearance		format Number of subjects tested				
Message Verbiage	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**	**G+T+ASD 20**	**G+IT+ASD 8**
CLIMB TO REACH [level] AT OR BEFORE [position]. AT [position] PROCEED DIRECT TO [position].	UM27, UM77	*	*	*	*	*
TURN [direction] [degrees] DEGREES. CLIMB TO [level]. REJOIN ROUTE AT OR BEFORE [position]	UM215, UM20, UM68	*	*	*	*	
FLY HEADING [degrees]. CLIMB TO [level]. TURN [direction] [degrees] DEGREES.	UM190, UM20, UM215	*	*	*	*	
AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE AT OR BEFORE [position].	UM65, UM68	*	*	*		*

Mean Response Time

The ANOVA for mean response time is summarized in Table 24. The main effects response (p = <0.0001) and format (p = 0.0024), and the interaction format*response (p = <0.0001) were statistically significant.

Table 24 Four Element ANOVA Summary for Response Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
response	1	1193.5	1193.5	40.66	<.0001*
format	4	2095.4	523.86	4.67	0.0024*
format*response	4	1163	290.75	9.9	<.0001*

The performance of subjects measured in response time is shown in Figure 39. The subjects correctly rejected (x = 9.87 sec) clearances significantly faster than correctly accepting (x = 12.56 sec) them. The mean response time as a function of format is illustrated in Figure 40 with letters denoting significant differences. The Tukey adjustment for format (Table 25) revealed that there are two significant differences: G+T+updUM resulted in significantly faster response times than TEXT and G+T+ASD. There were no other significant differences in format.

The Simple-Effect F-test listed in Table 26 indicated that all graphic formats (G+T, G+T+updUM, G+T+ASD, G+IT+ASD) resulted in significantly faster responses when correctly rejecting the clearance compared to correctly accepting a clearance. For the Text condition, there was no difference in mean response time between correct accepted and correct rejected answers. There was a significant interaction between format*response in G+T, G+T+updUM, G+T+ASD, and G+IT+ASD; pilots rejected clearances in less time than when accepting them. The magnitude of the difference is greatest for G+T+ASD followed by G+IT+ASD. The magnitude of the difference was similar for G+T and G+T+updUM. There was no significant difference for text, see Figure 41. Response times while using TEXT were no different when accepting or rejecting clearances.

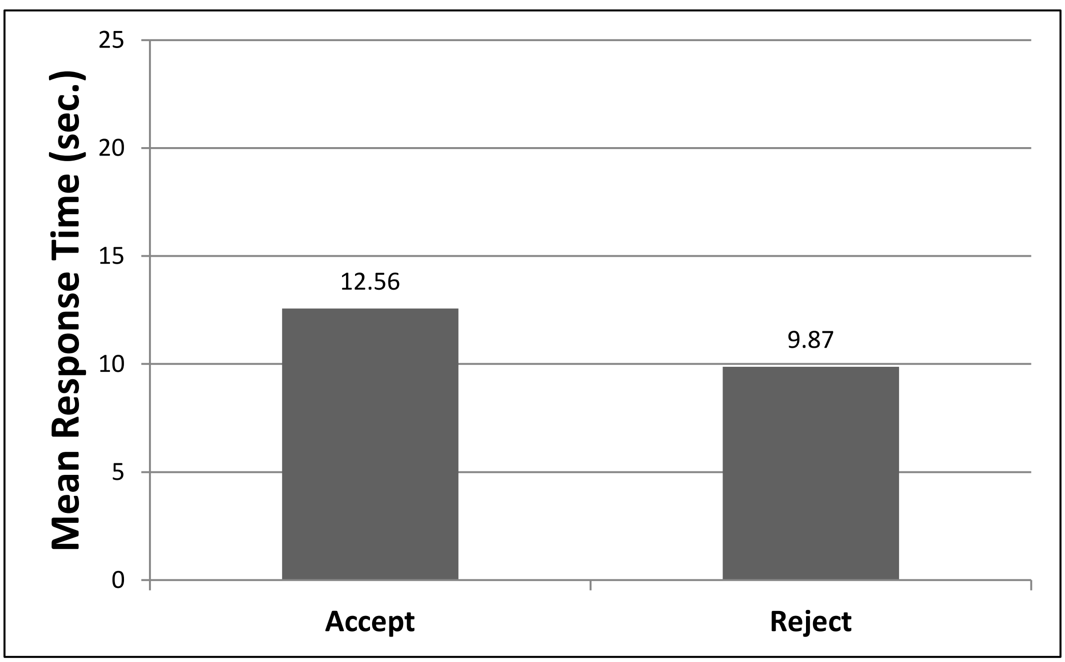


Figure 39 Four Element Mean Response Time as a Function of response

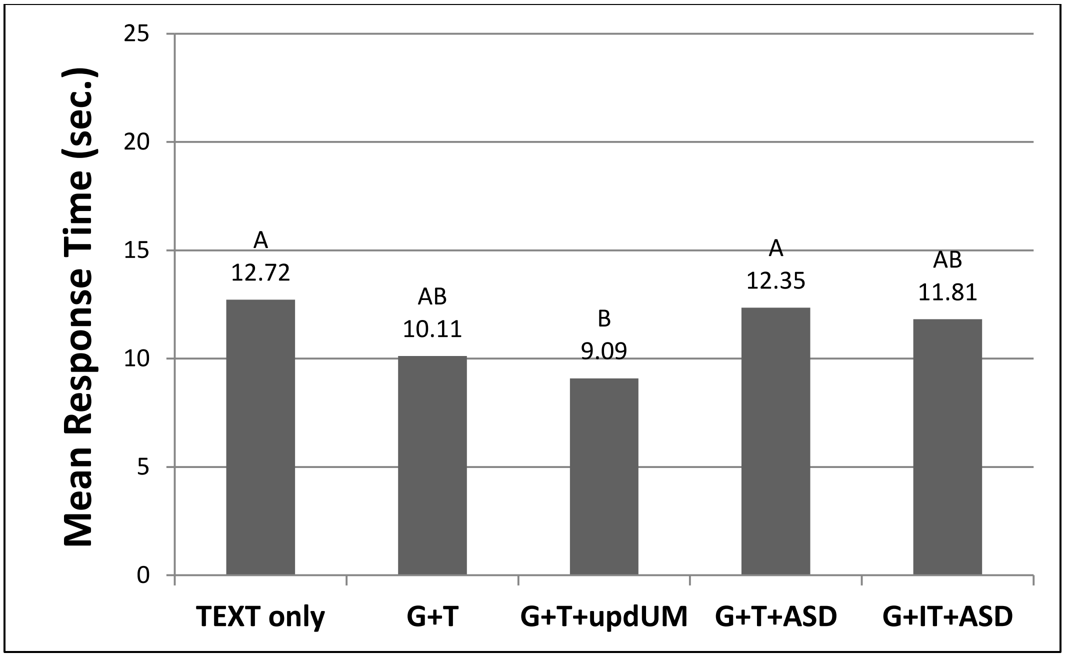


Figure 40 Four Element Mean Response Time as a Function of format

Table 25 Four Element Comparison of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	2.7074	1.3765	61	1.97	0.0538	Tukey-Kramer	0.2944
TEXT only	**G+T+updUM**	3.6521	1.1201	61	3.26	0.0018	Tukey-Kramer	.0151*
TEXT only	**G+T+ASD**	0.4435	1.139	61	0.39	0.6984	Tukey-Kramer	0.995
TEXT only	**G+IT+ASD**	0.9106	1.4844	61	0.61	0.5419	Tukey-Kramer	0.9724
G+T	**G+T+updUM**	0.9447	1.2165	61	0.78	0.4404	Tukey-Kramer	0.9364
G+T	**G+T+ASD**	-2.264	1.234	61	-1.83	0.0714	Tukey-Kramer	0.3636
G+T	**G+IT+ASD**	-1.797	1.5585	61	-1.15	0.2534	Tukey-Kramer	0.7777
G+T+updUM	**G+T+ASD**	-3.209	0.9394	61	-3.42	0.0011	Tukey-Kramer	.0097*
G+T+updUM	**G+IT+ASD**	-2.742	1.3374	61	-2.05	0.0447	Tukey-Kramer	0.2553
G+T+ASD	**G+IT+ASD**	0.4671	1.3533	61	0.35	0.7312	Tukey-Kramer	0.9969

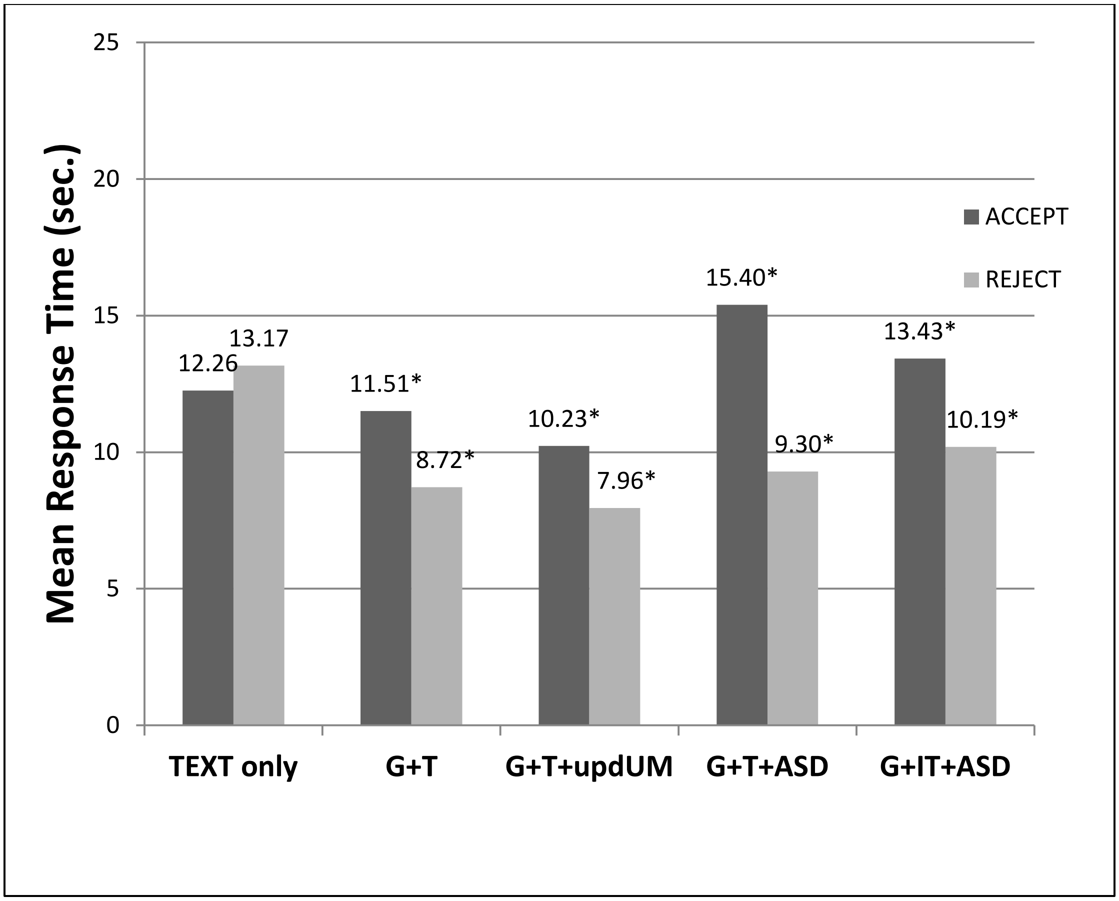


Figure 41 Four Element Mean Response Time as a Function of format*response

Table 26 Four Element format*response Interaction Sliced by format for Response Time

format	DF	Sum of Squares	Mean Square	F Value	Pr > F
TEXT only	1	32.179968	32.179968	0.88	0.3475
G+T	1	229.280456	229.280456	6.3	0.0183*
G+T+updUM	1	391.982306	391.982306	10.77	0.0017*
G+T+ASD	1	2061.59815	2061.598153	56.62	<.0001*
G+IT+ASD	1	151.761829	151.761829	4.17	0.0315*

Mean Percent Correct

The ANOVA results for mean percent correct for four element clearances as a function of graphic condition are presented in Table 27. The results indicated a significant main effect of response ($p < .0001$). The main effect for format was nearly significant at $p = 0.0509$.

Table 27 Four Element ANOVA Summary for Percent Correct

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
response	1	61	60.23	<.0001*
format	4	61	2.51	0.0509
format*response	4	61	0.52	0.7236

The difference between the two response types is illustrated in Figure 42. Subjects correctly rejected (x = 93%) clearances more often than correctly accepted them (x = 70.52%). There were no other statistically significant results.

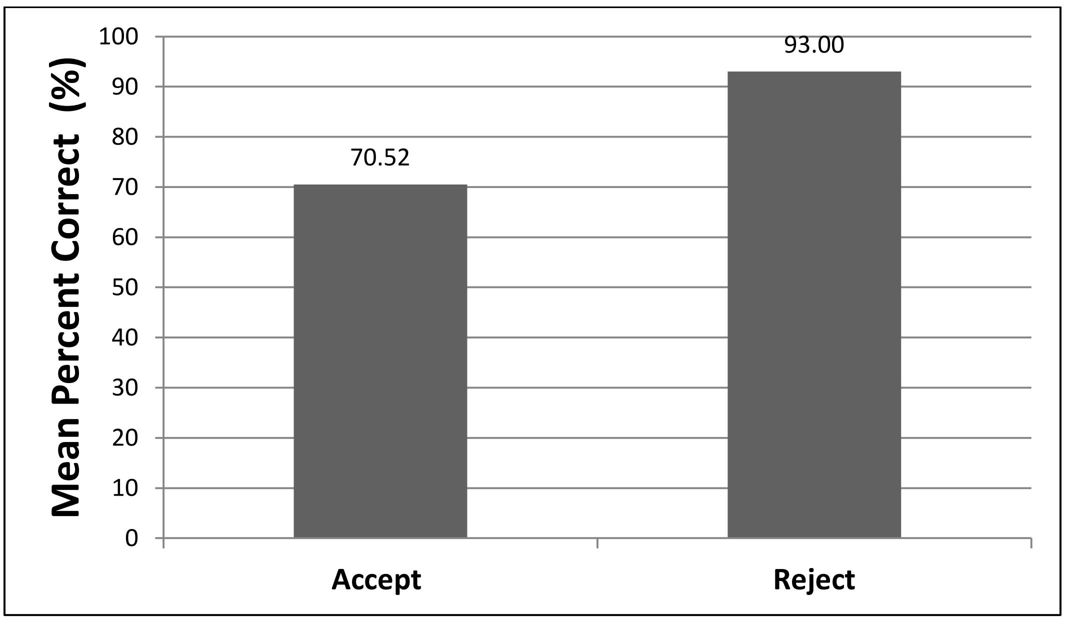


Figure 42 Four Element Mean Percent Correct as a Function of response

FIVE ELEMENT CLEARANCES

Three different clearances with five elements each were tested across all five formats and are listed in Table 28.

Table 28 Five Element Clearance Breakdown by format

Clearance		format Number of subjects tested				
Message Verbiage	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**	**G+T+ASD 20**	**G+IT+ASD 8**
AT [position] PROCEED DIRECT TO [position]. AT [position] DESCEND TO [level]. Fly HEADING [degrees]	UM77, UM25, UM190	*	*	*	*	*
CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM79, UM339	*	*	*		
CLIMB TO REACH [level] AT OR BEFORE [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE AT OR BEFORE [position]	UM27, UM97, UM68	*	*	*	*	*

Mean Response Time

Table 29 summarizes the ANOVA for mean response time. Results indicated that both main effects (response, p = <.0001, format, p = <.0001) and the interaction (p = 0.0005) were statistically significant.

Table 29 Five Element ANOVA Summary of Response Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
response	1	2446.82941	2446.829412	48.01	<.0001*
format	4	5393.84237	1348.460592	11.41	<.0001*
format*response	4	1199.47799	299.869498	5.88	0.0005*

Pilots correctly rejected (x = 12.09) clearances in less time than correctly accepting clearances (x = 16.19). Figure 43 illustrates the means. The results of the post-hoc Tukey-Kramer test for format (Table 30) revealed that the pilot response time was significantly slower when using TEXT and G+T+ASD compared to the other three formats as illustrated in Figure 44.

The results of the Simple-Effects F-test for the interaction response*format shown in Table 31 and Figure 45 indicates that all four graphic formats resulted in significantly faster mean response time to correctly rejected clearances when compared to correctly accepted clearances. The interaction also indicated that this difference varies based on graphic format. There was a significant interaction between format*response in G+T, G+T+updUM, G+T+ASD, and G+IT+ASD; pilots rejected clearances in less time than accepting them. Again the magnitude of this difference varies by format with G+T+ASD resulting in the largest difference (7.32 seconds) and G+T+updUM with the lowest (3.85 seconds). There was no significant difference for text. Response times while using TEXT were no different when accepting or rejecting clearances.

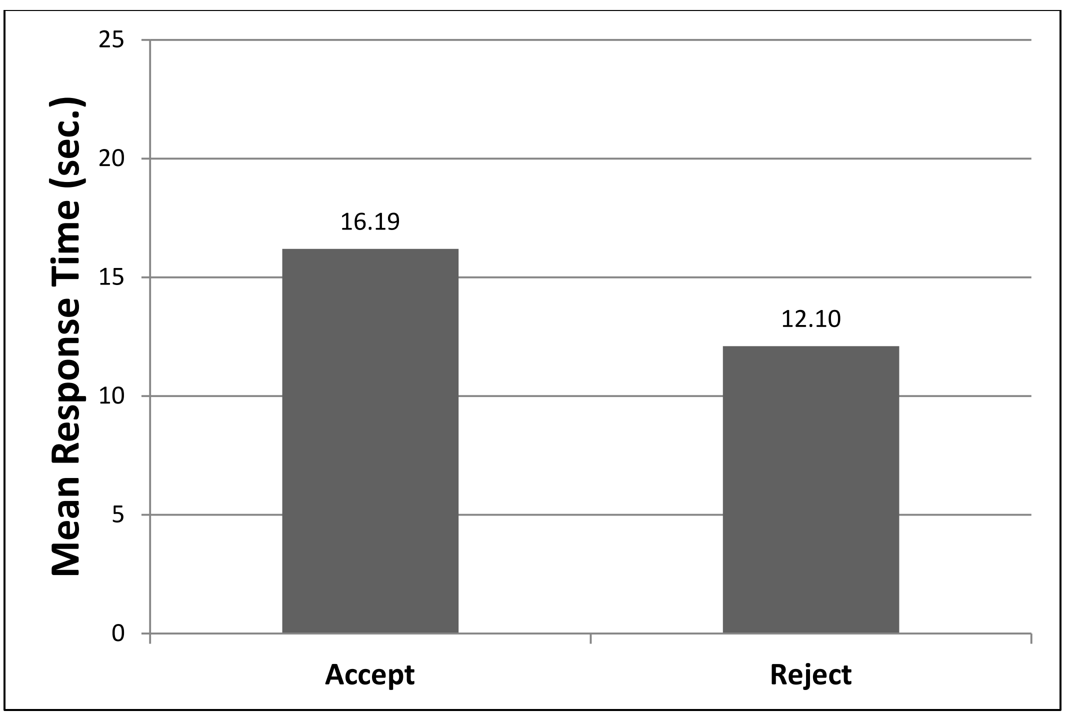


Figure 43 Five Element Mean Response Time as a Function of response

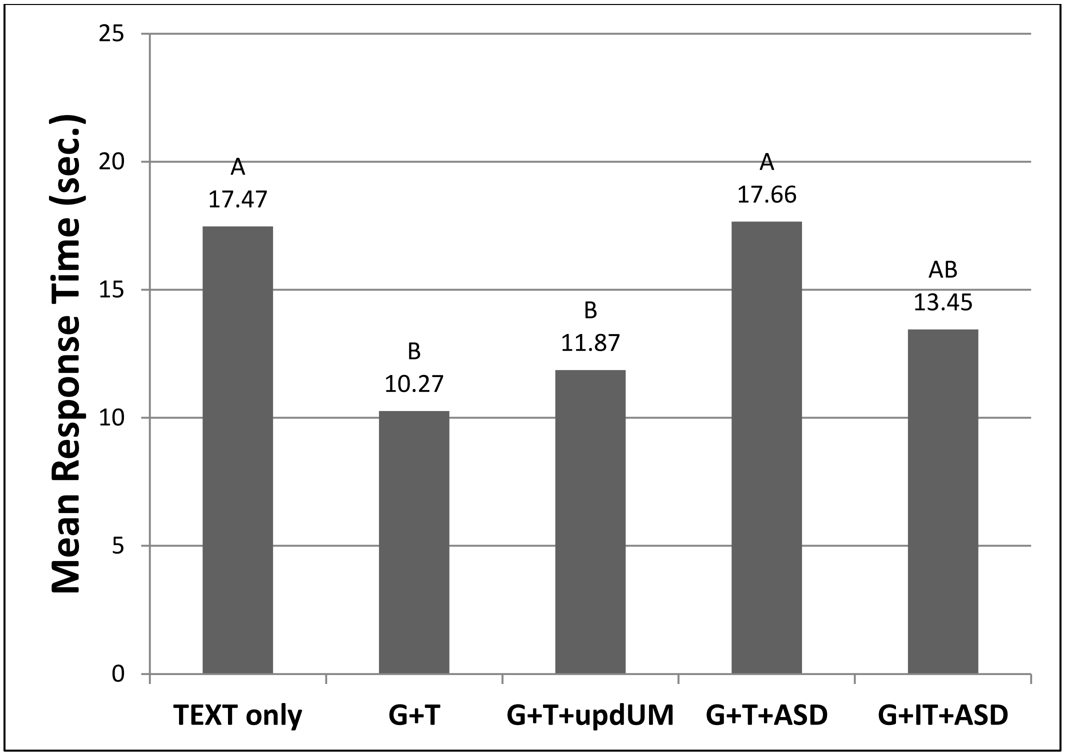


Figure 44 Five Element Mean Response Time as a Function of format

Table 30 Five Element Comparison of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	7.1699	1.5843	61	4.53	<.0001	Tukey-Kramer	.0003*
TEXT only	**G+T+updUM**	5.5576	1.2855	61	4.32	<.0001	Tukey-Kramer	.0005*
TEXT only	**G+T+ASD**	0.1182	1.3459	61	0.09	0.9303	Tukey-Kramer	1
TEXT only	**G+IT+ASD**	4.1227	1.582	61	2.61	0.0115	Tukey-Kramer	0.0818
G+T	**G+T+updUM**	-1.6123	1.3982	61	-1.15	0.2534	Tukey-Kramer	0.7776
G+T	**G+T+ASD**	-7.0516	1.4538	61	-4.85	<.0001	Tukey-Kramer	.0001*
G+T	**G+IT+ASD**	-3.0472	1.6748	61	-1.82	0.0738	Tukey-Kramer	0.372
G+T+updUM	**G+T+ASD**	-5.4394	1.1208	61	-4.85	<.0001	Tukey-Kramer	.0001*
G+T+updUM	**G+IT+ASD**	-1.435	1.3955	61	-1.03	0.3079	Tukey-Kramer	0.8413
G+T+ASD	**G+IT+ASD**	4.0044	1.4513	61	2.76	0.0076	Tukey-Kramer	0.0568

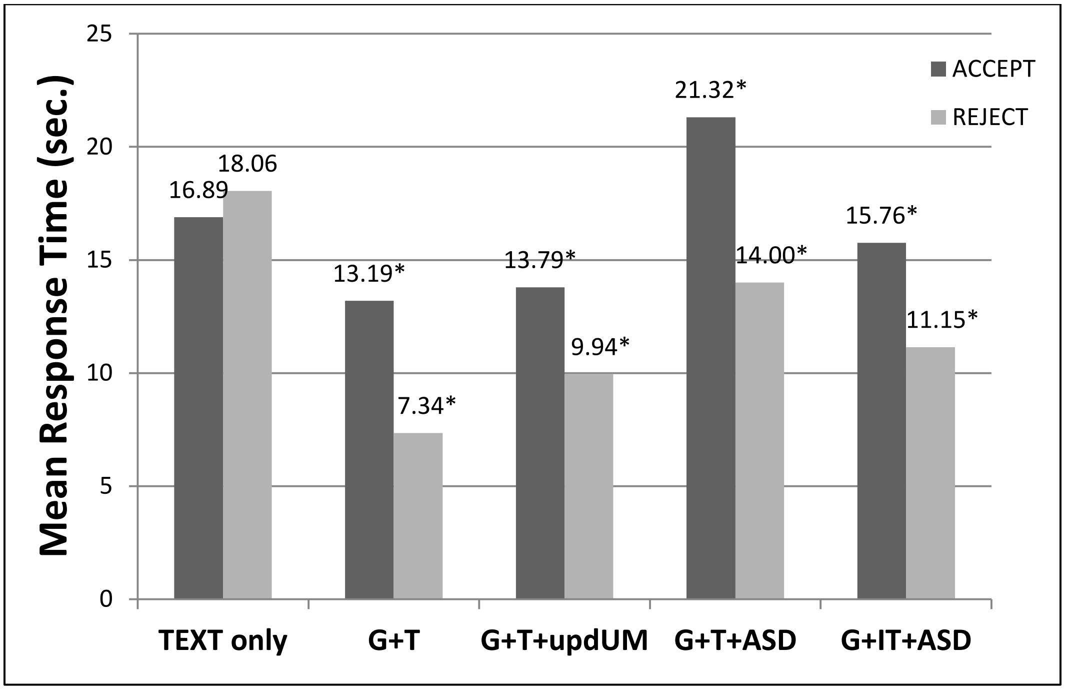


Figure 45 Five Element Mean Response Time as a Function of format*response

Table 31 Five Element format*response Interaction Sliced by format for Response Time

format	DF	Sum of Squares	Mean Square	F Value	Pr > F
TEXT only	1	38.497525	38.497525	0.67	0.4129
G+T	1	737.073067	737.073067	12.85	0.0004*
G+T+updUM	1	848.018475	848.018475	14.79	0.0001*
G+T+ASD	1	1759.63513	1759.635128	30.69	<.0001*
G+IT+ASD	1	463.857097	463.857097	8.09	0.0046*

Mean Percent Correct

The ANOVA results, summarized in Table 32, indicated that the response and format main effects were statistically significant as was the interaction format*response. For the main effect response, the analysis indicated that pilots correctly rejected (x = 93.08%) clearances with more accuracy than correctly accepting (x = 79.08%) them (see Figure 46). The format main effect grouping is illustrated in Figure 47 and the Tukey-Kramer post-hoc analysis is presented in Table 33.

Table 32 Five Element ANOVA Summary for Percent Correct

Effect	Num DF	Den DF	F Value	Pr > F
response	1	61	31.69	<.0001*
format	4	61	4.71	0.0022*
format*response	4	61	3.96	0.0064*

The Tukey-Kramer analysis (Table 33) indicated that mean percent correct for TEXT was significantly lower than G+IT+ASD (p = 0.0192). G+T and G+T+ASD were not significantly different from one another, but were both significantly different (lower percent correct) than G+IT+ASD (see Figure 47).

The Simple-Effects F-test analysis (Table 34) indicated that mean percent correct rejections were significantly higher for four of the five conditions. The only condition that had no difference was G+IT+ASD. With respect to the interaction, the difference between correct accept and correct rejects was largest for Text followed by G+T. For the format G+T+updUM the mean percent correct accepts increased over that of G+T and G+T+ASD. G+IT+ASD the mean percent correct accept and reject were not different and both result in high accuracy. This indicated that integrated text did increase performance considering the difference between that condition and G+T+ASD.

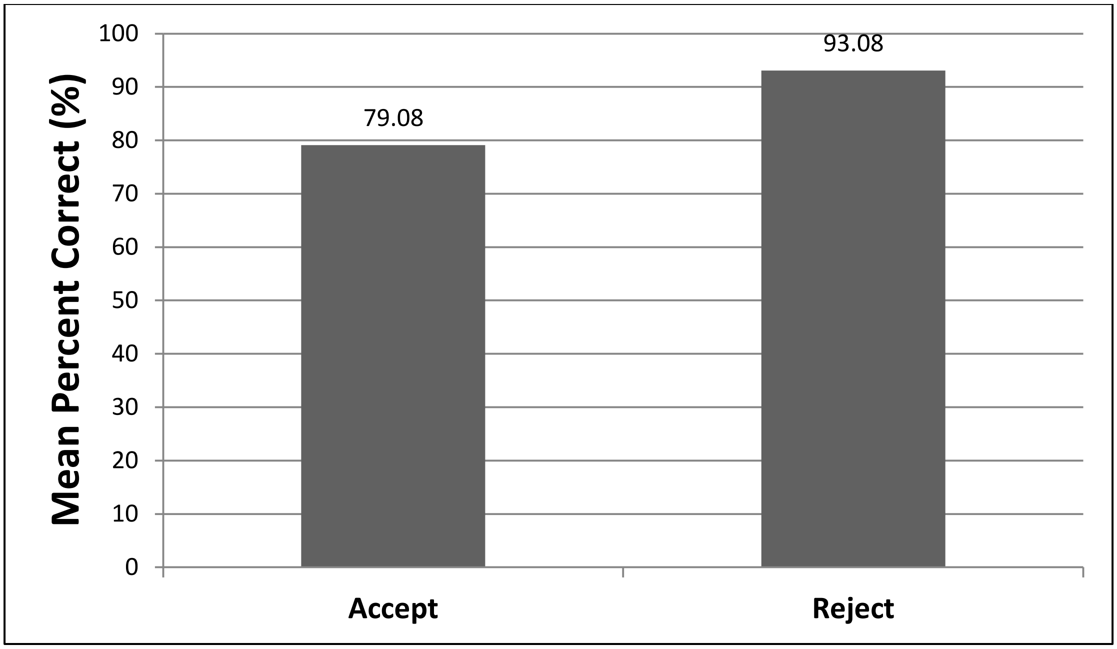


Figure 46 Five Element Mean Percent Correct as a Function of response

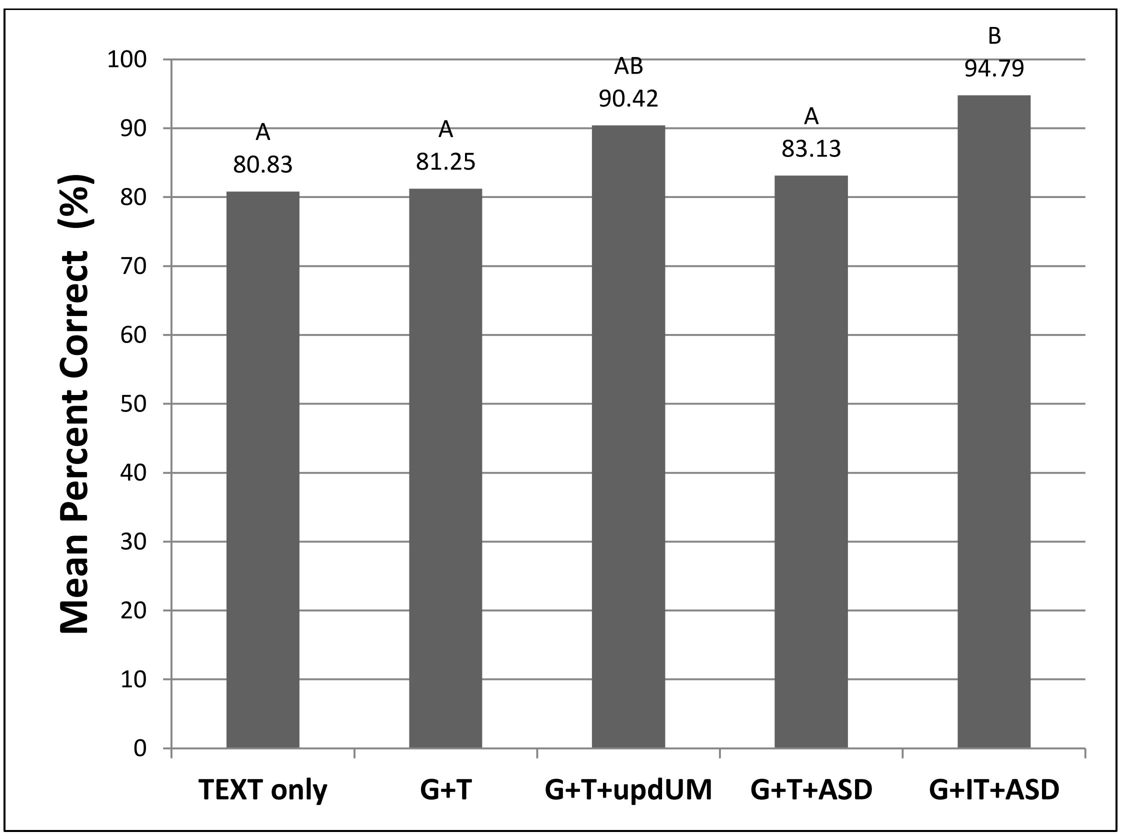


Figure 47 Five Element Mean Percent Correct as a Function of format

Table 33 Five Element Comparison for Percent Correct for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	-0.417	4.3965	61	-0.09	0.9248	Tukey-Kramer	1
TEXT only	**G+T+updUM**	-9.583	3.5898	61	-2.67	0.0097	Tukey-Kramer	0.0705
TEXT only	**G+T+ASD**	-2.292	3.5898	61	-0.64	0.5256	Tukey-Kramer	0.9681
TEXT only	**G+IT+ASD**	-13.96	4.3965	61	-3.17	0.0024	Tukey-Kramer	.0192*
G+T	**G+T+updUM**	-9.167	3.8774	61	-2.36	0.0213	Tukey-Kramer	0.1393
G+T	**G+T+ASD**	-1.875	3.8774	61	-0.48	0.6304	Tukey-Kramer	0.9886
G+T	**G+IT+ASD**	-13.54	4.6344	61	-2.92	0.0049	Tukey-Kramer	.0377*
G+T+updUM	**G+T+ASD**	7.2917	2.931	61	2.49	0.0156	Tukey-Kramer	0.1069
G+T+updUM	**G+IT+ASD**	-4.375	3.8774	61	-1.13	0.2636	Tukey-Kramer	0.791
G+T+ASD	**G+IT+ASD**	-11.67	3.8774	61	-3.01	0.0038	Tukey-Kramer	.0301*

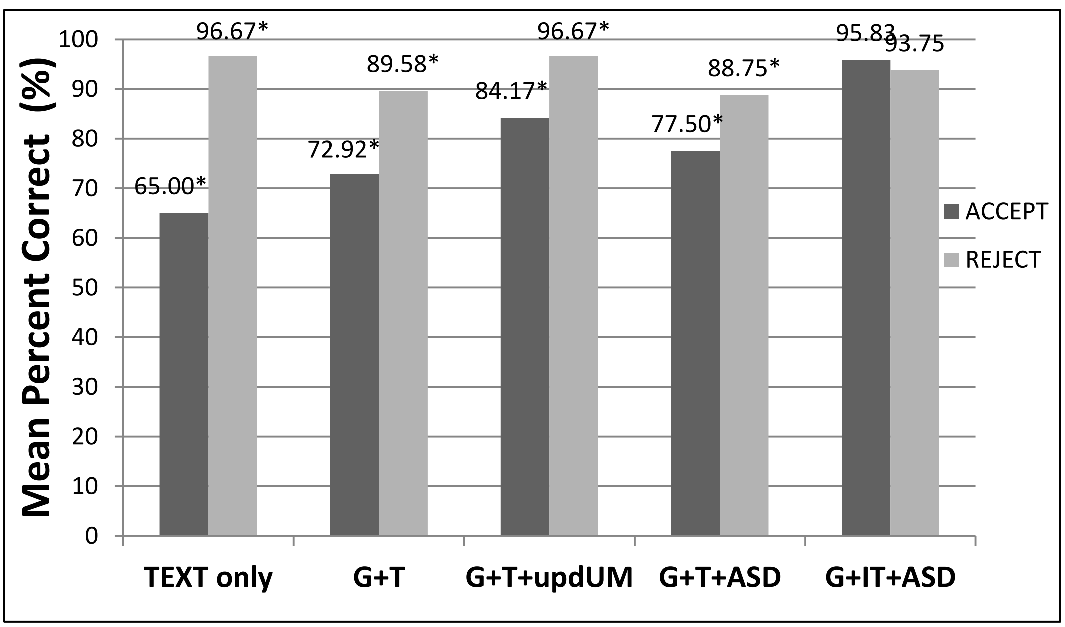


Figure 48 Five Element Mean Percent Correct as a Function of format*response

Table 34 Five Element format*response Interaction Sliced by format for Percent Correct

Effect	format	Num DF	Den DF	F Value	Pr > F
format*response	TEXT only	1	61	29.18	<.0001*
format*response	G+T	1	61	6.47	0.0135*
format*response	G+T+updUM	1	61	9.09	0.0037*
format*response	G+T+ASD	1	61	7.37	0.0086*
format*response	G+IT+ASD	1	61	0.1	0.7517

SIX ELEMENT CLEARANCES

Table 35 lists the two concatenated six element clearances tested across all five formats.

Table 35 Six Element Clearance Breakdown by format

Clearance		format Number of subjects tested				
Message Verbiage	UM Number	Text 10	G+T 8	G+T+updUM 20	G+T+ASD 20	G+IT+ASD 8
AT [level] PROCEED DIRECT TO [position]. AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE AT OR BEFORE [position].	UM78, UM65, UM68	*	*	*	*	*
DESCEND TO [level]. AT [level] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [DEGREES]. REJOIN ROUTE AT OR BEFORE [position].	UM23, UM78, UM97, UM68	*	*	*	*	*

Mean Response Time

The ANOVA for mean response time is summarized in Table 36. Results indicated that both main effects, response (p = 0.0062) and format (p = 0.0007), were statistically significant. For format, pilots correctly reject clearances in less time than they correctly accepted them as illustrated in Figure 49. The Tukey-Kramer test for format listed in Table 37 indicates that there are two significant differences among formats. Mean response time for G+T and G+T+updUM were not significantly different from each other but were significantly different from G+T+ASD, which resulted in the longest mean response time. G+T+ASD format was not significantly different from Text or G+IT+ASD format. Figure 50 illustrates the results and a letter above each bar indicates significant differences. There was no significant interaction.

Table 36 Six Element ANOVA Summary for Response Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
response	1	810.59	810.59	8.11	0.0062*
format	4	3322.9	830.73	5.43	0.0007*
format*response	4	680	170	1.7	0.1775

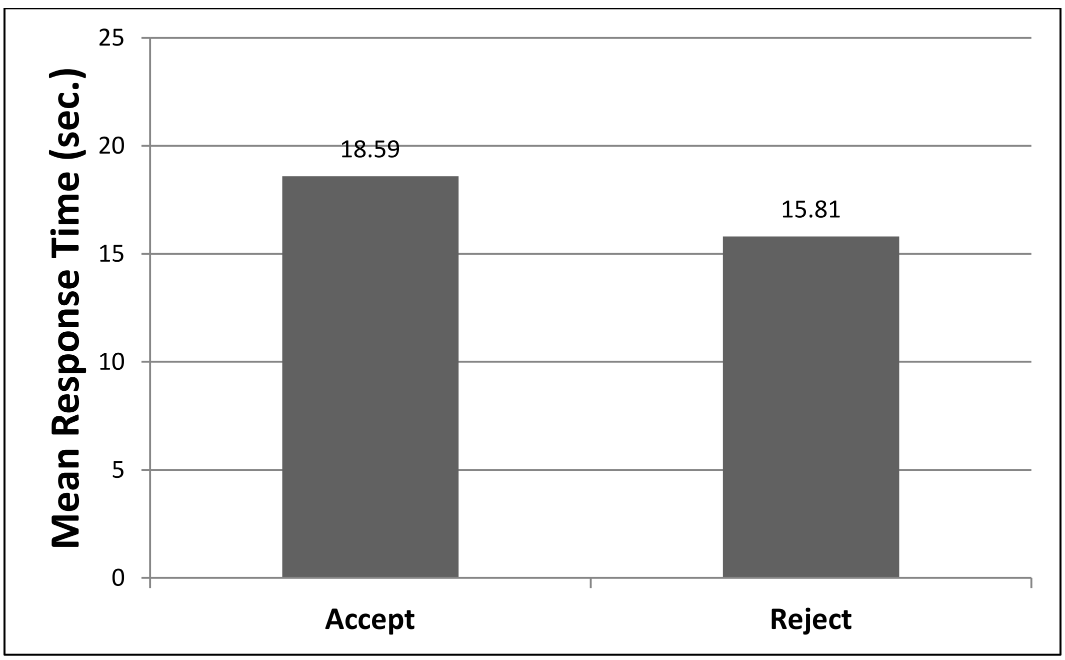


Figure 49 Six Element Mean Response Time as a Function of response

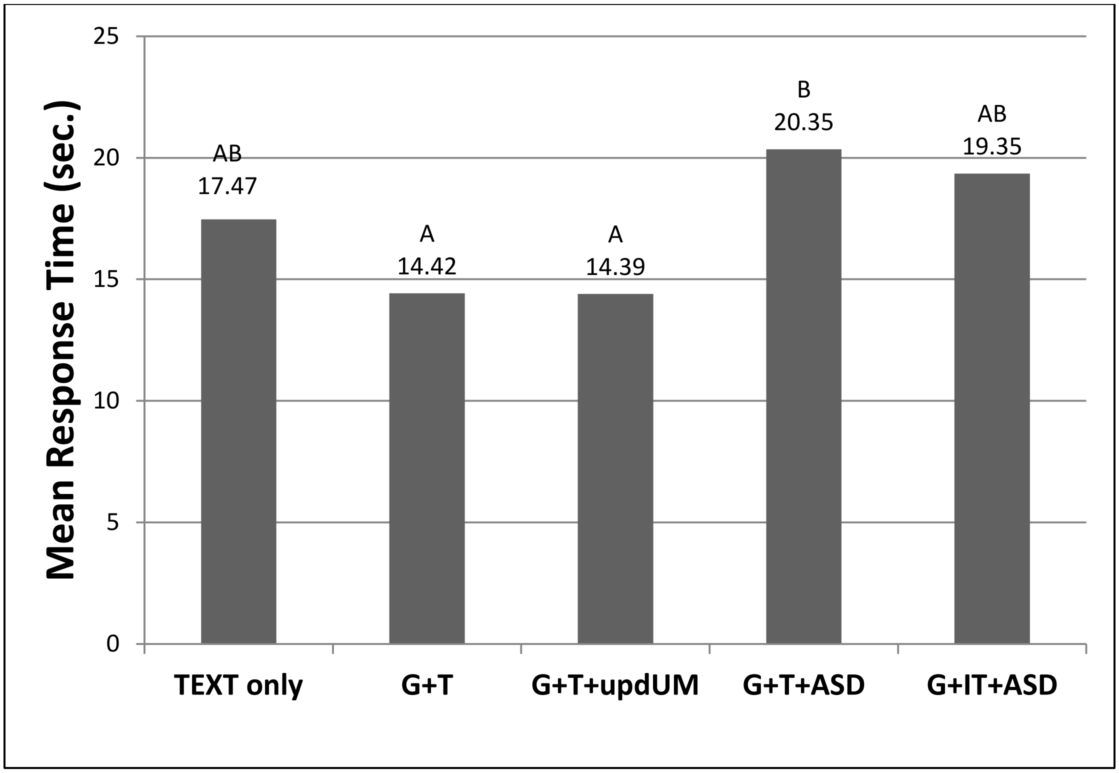


Figure 50 Six Element Mean Response Time as a Function of format

Table 37 Six Element Comparison of Response Time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	3.2131	2.1489	61	1.5	0.14	Tukey-Kramer	0.5695
TEXT only	**G+T+updUM**	3.1522	1.7409	61	1.81	0.0751	Tukey-Kramer	0.377
TEXT only	**G+T+ASD**	-2.786	1.7409	61	-1.6	0.1148	Tukey-Kramer	0.5032
TEXT only	**G+IT+ASD**	-1.841	2.1538	61	-0.85	0.3962	Tukey-Kramer	0.9121
G+T	**G+T+updUM**	-0.061	1.9039	61	-0.03	0.9746	Tukey-Kramer	1
G+T	**G+T+ASD**	-5.999	1.9039	61	-3.15	0.0025	Tukey-Kramer	.0205*
G+T	**G+IT+ASD**	-5.054	2.2875	61	-2.21	0.0309	Tukey-Kramer	0.1902
G+T+updUM	**G+T+ASD**	-5.938	1.4276	61	-4.16	0.0001	Tukey-Kramer	.0009*
G+T+updUM	**G+IT+ASD**	-4.993	1.9095	61	-2.61	0.0112	Tukey-Kramer	0.0802
G+T+ASD	**G+IT+ASD**	0.945	1.9095	61	0.49	0.6224	Tukey-Kramer	0.9876

Mean Percent Correct

The ANOVA from mean percent correct for six elements is summarized in Table 38. The results indicated there was a statistically significant difference for the main effect of response. Pilots correctly rejected clearances (x = 87.25%) with more accuracy than correctly accepted them (x = 75.63%). Figure 51 illustrates the mean values of the main effect.

Table 38 Six Element ANOVA Summary of Percent Correct

Effect	Num DF	Den DF	F Value	Pr > F
response	1	61	6.45	0.0136*
format	4	61	2.02	0.1028
format*response	4	61	0.37	0.8286

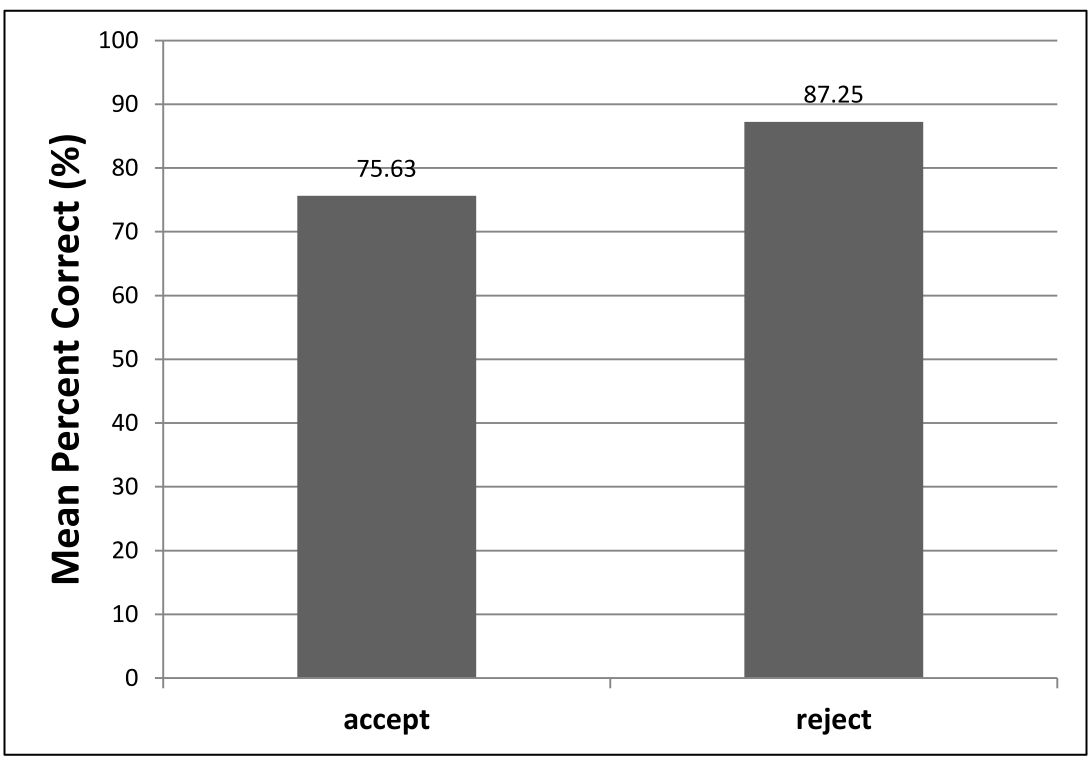


Figure 51 Six Element Mean Percent Correct as a Function of response

NINE ELEMENT CLEARANCES

A single nine element concatenated clearance was tested across three formats as listed in Table 39.

Table 39 Nine Element Clearance Breakdown by format

Clearance		format Number of subjects tested		
Message Verbiage	**UM Number**	**Text 10**	**G+T 8**	**G+T+updUM 20**
AT [position] CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]	UM339, UM339, UM339	*	*	*

Mean Response Time

The ANOVA analysis is summarized in Table 40. Results indicated that both main effects, response (p = <.0001) and format (p = <.0001), and the interaction format*response (p = 0.0474) were statistically significant. The main effect of response indicated that pilots responded in less time when correctly rejecting a clearance (x = 12.48) compared to correctly accepting a clearance (x = 17.18), see Figure 52. The main effect of format and means are illustrated in Figure 53.

Table 41 summarizes the post-hoc Tukey-Kramer analysis for the main effect format. Figure 53 illustrates the results that indicated that the Text format resulted in significantly higher mean response times as compared to G+T and G+updUM. The response time difference was almost 15 seconds between Text and G+T. There was not a significant different between the G+T and G+T+updUM.

Table 40 Nine Element ANOVA Summary for Response Time

Source	DF	Type III SS	Mean Square	F Value	Pr > F
response	1	669.56	669.56	33.89	<.0001*
format	2	3721.2	1860.6	31.23	<.0001*
format*response	2	287.42	143.71	7.27	0.0474*

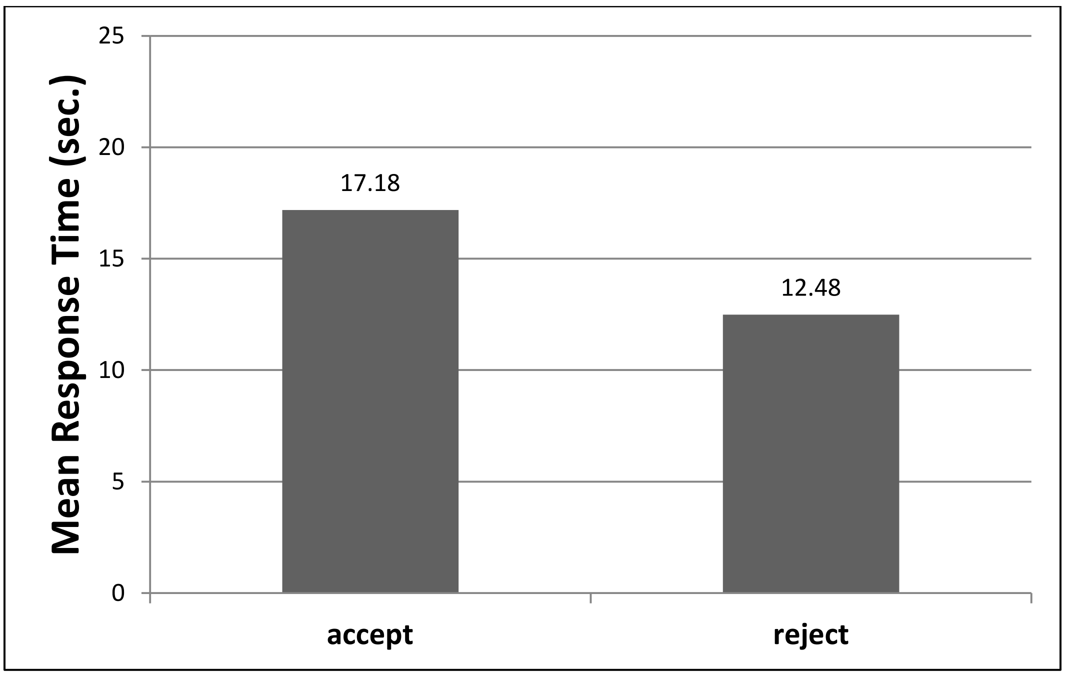


Figure 52 Nine Element Mean Response Time as a Function of response

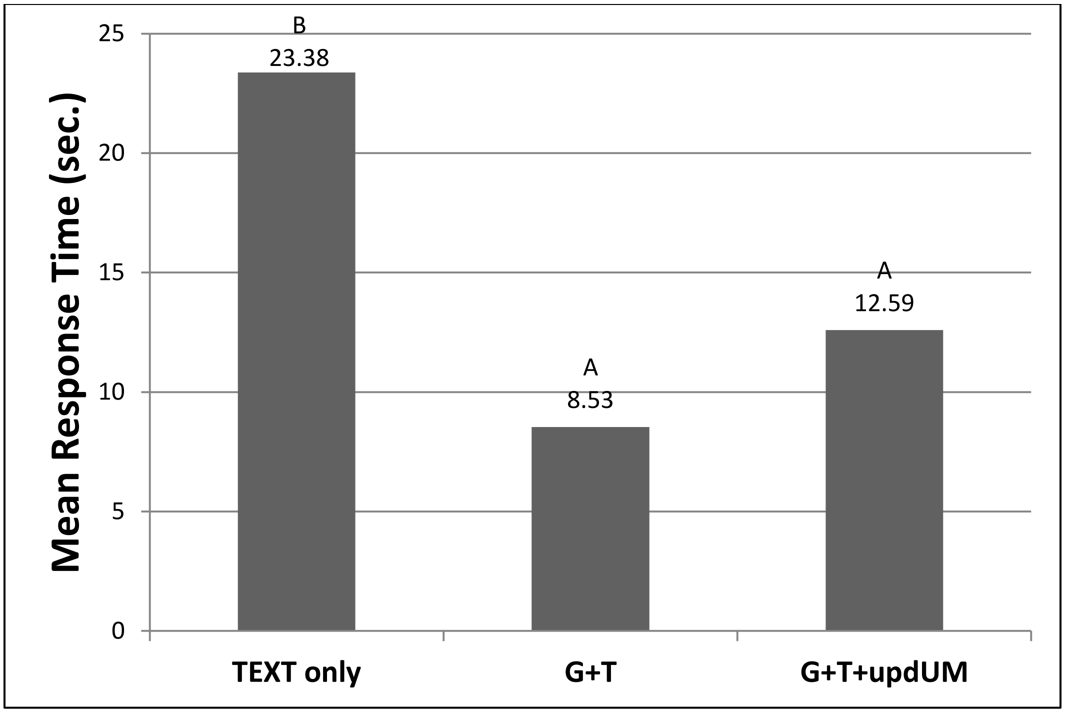


Figure 53 Nine Element Mean Response Time as a Function of format

Table 41 Nine Element Comparison of Response time for format Main Effect

format	format	Estimate	Standard Error	DF	tValue	Pr> |t|	Adj	Adj P
TEXT only	**G+T**	14.844	1.9221	34	7.72	<.0001	Tukey-Kramer	.0001*
TEXT only	**G+T+upd UM**	10.791	1.5608	34	6.91	<.0001	Tukey-Kramer	.0001*
G+T	**G+T+upd UM**	-4.053	1.6872	34	-2.4	0.0219	Tukey-Kramer	0.0556

The Simple-Effects F-test results are listed in Table 42. Results indicated that for Text there was no difference in correct accept or correct reject response times. There was a significant difference in response time for G+T ($p = 0.0022$) and G+T+updUM ($p = <0.0001$), with both conditions resulting in faster correct rejections. However, G+T resulted in a greater difference between correct accept and correct reject (difference = 7.35 sec) and overall lower mean response times for both correct accept and reject compared to G+T+ updUM. For G+T+updUM the difference was 6.16 sec. Figure 54 illustrates the significant interaction.

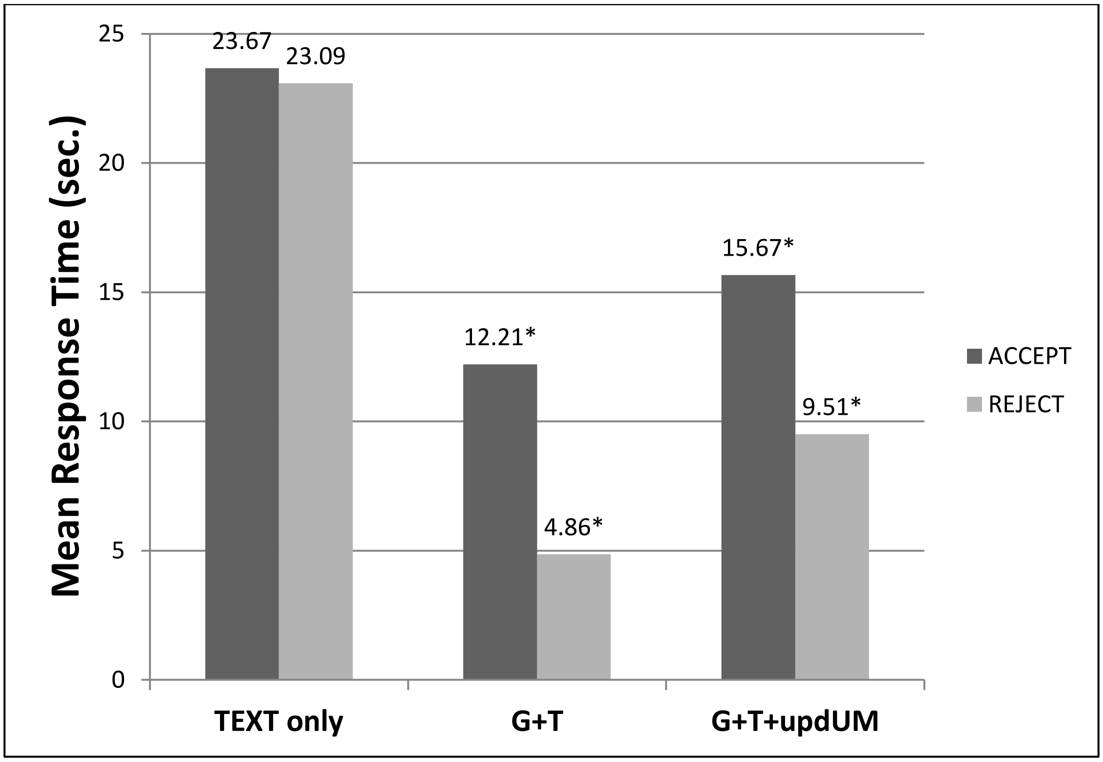


Figure 54 Nine Element Mean Response Time as a Function of format*response

Table 42 Nine Element format*response Interaction Sliced by format for Percent Correct

Effect	format	Num DF	Den DF	F Value	Pr > F
format*response	TEXT only	1	34	0.09	0.7717
format*response	G+T	1	34	10.95	0.0022*
format*response	G+T+updUM	1	34	20.02	<.0001*

Mean Percent Correct

The ANOVA for mean percent correct is summarized in Table 43. The results indicated a significant main effect of response. There were no other significant effects. The mean percent correct for correct rejects (x= 94.17%) is significantly higher than for correct accepts (x = 45.83%) as illustrated in Figure 55.

Table 43 Nine Element ANOVA Summary of Percent Correct

Effect	Num DF	Den DF	F Value	Pr > F
response	1	35	47.89	<.0001*
format	2	35	0.13	0.8787
format*response	2	35	1.05	0.3597

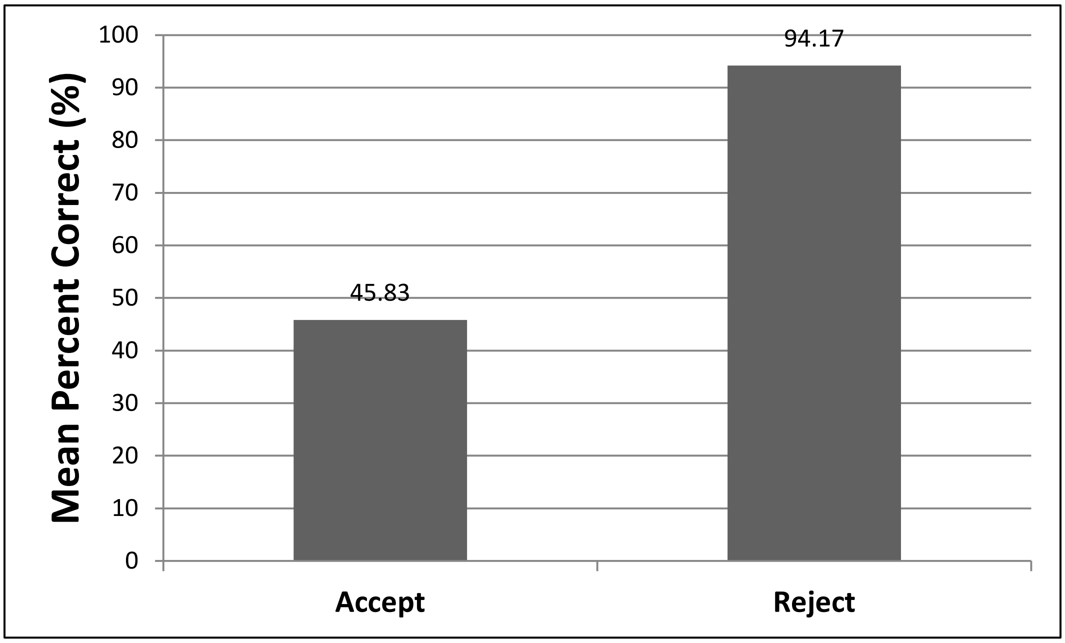


Figure 55 Nine Element Mean Percent Correct as a Function of response

SUBJECTIVE PILOT INPUT

During testing pilot's verbal comments were recorded. Listed below, a summary of the most frequent and relevant pilot comments:

- All clearances that contained the "REJOIN" UM had an execution issue. Pilots explained that when they are off their original route and they need to rejoin their original route they needed a specific point for the rejoin. Pilots indicated that when REJOIN is paired with "BEFORE PASSING" a large range of possibilities exist. The pilot could rejoin at his discretion. Pilots recommended that instead of using “BEFORE PASSING” use “REJOIN by (POSITION)” or “REJOIN ABEAM (POSITION)”. This limited the pilot’s options and reduced ambiguity and confusion when the “REJOIN” UM was used.

- The “HEADING” element in a UM also resulted in many pilot comments. The pilots commented that traditionally when a heading message was used alone it serves the purpose to deviate immediately, but momentarily due to traffic. Pilots always expect verbal instructions shortly after they execute the clearance. During the experiment, pilots were concerned that while understanding the scenario, they felt that the clearance deviated them from their route if there was no follow up message from the air traffic controller. Pilot recommendations were to always couple the heading message with re-routing clearance message such as “Proceed Direct to” or “Rejoin Route at”.
- When pilots were asked about the use of graphics within a ND format, most pilots 98% indicated it would be beneficial in real life situations. They found the graphic symbols to be very useful. Many said that it helped them recognize a faulty clearance quicker when compared to text. They also stated that it supported their cognitive process when dealing with longer clearances. The green line indicating the new route was considered the most useful graphic by many pilots.
- Pilots commented that the ASD below the ND did not help them. They felt the information was redundant. Only about 3 pilots thought it was helpful. The statistical results showed it slowed response time.

VI. DISCUSSION

In the NextGen Airspace System DataComm between ATC and the flight deck will include the use of data link which allows clearances to be sent from ATC to pilot's flight deck displays and DMs from the pilot to ATC's displays. Text and voice clearance formats **alone do not ideally support effective air-ground communications**, particularly by increasing the risk of human error when communicating longer trajectory clearances such as 4D clearances. This research evaluated the use of different graphic formats to convey uplink clearance messages.

1ST ESSENTIAL PREDICTION

Based on the reference analysis on text and graphics for DataComm the prediction is that; Clearance interpretation will occur more quickly and accurately while using graphics and text rather than text only as a communication format when transmitting clearances with more than one element.

The differences between TEXT and G+T were examined and the results show several trends and patterns. In general, results indicated that graphics did have a positive impact on interpretability measured in response time and percent correct, see Figure 56 and 57. When TEXT was compared to G+T pilot's response time was lower and percent correct was higher when using G+T. The difference in response time was significant while interpreting clearances containing 3, 5, and 9 elements, see table 44.

Table 44 Summary of Differences

Summary of Differences - Text vs. G+T							
(*) Indicates significant difference (+) indicates better performance with G+T (-) indicates better performance with Text							
Elements / DV	One	Two	Three	Four	Five	Six	Nine
Response Time	+	+	*+	+	*+	+	*+
Percent Correct	+	+	*+	+	+	+	-

There is a trend shown by the lines of best fit in figure 56; as the number of elements increase in a clearance, graphics allowed pilots to interpret clearances in less time than when using text. Figure 57 shows that percent correct answers was higher while using graphics. Table 44 shows that while communicating 3 element clearances the difference in percent correct was significant.

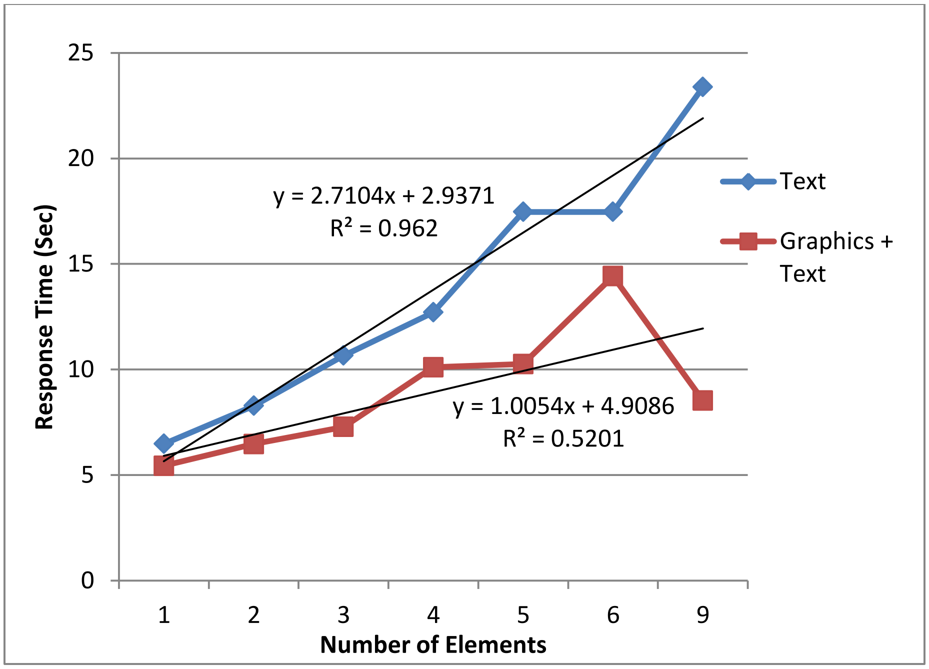


Figure 56 Performance of TEXT vs. G+T on Response Time

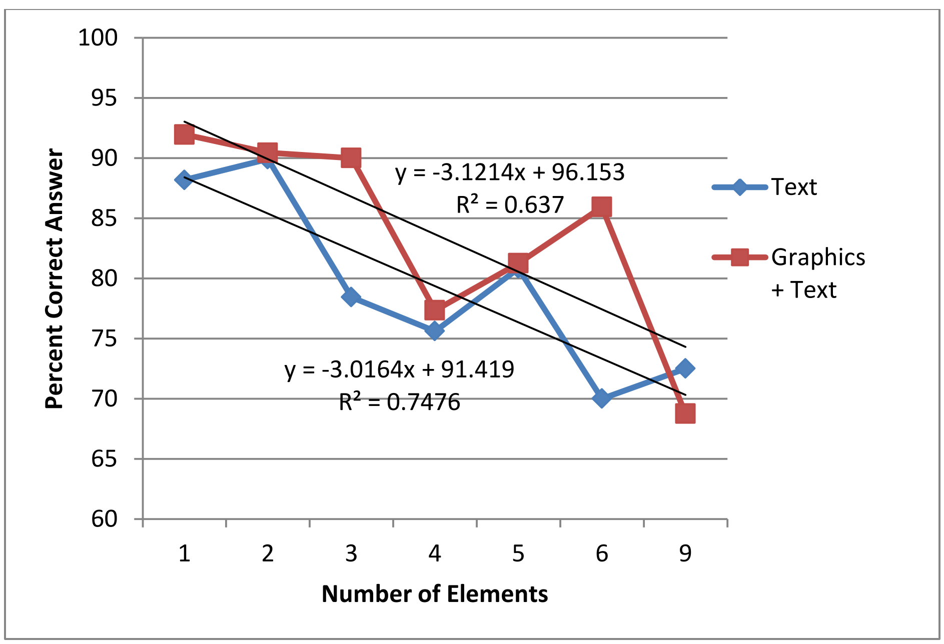


Figure 57 Performance of TEXT vs. G+T on Percent Correct

As pointed out by Chang, Andre, and Foyle (2009), TBO clearances in the future NAS will become more complex and lengthy. The results showed that as the number of elements in a clearance increase response time increases. This is expected but results showed that the slope of the increase differed between text and graphics with graphics showing a smaller slope. Note that in a clearance the number of elements does not indicate complexity but only length and amount of information. With that being said a pattern is not apparent when comparing percent correct answers. Percent correct for text vs G+T was only significantly different under the three element condition. Percent rates were generally higher while using G+T vs. text only, except when using nine element clearances. The results suggest that future research is needed to more clearly understand mean percent correct. While the projection for the future communication is to increase information content in clearances, graphics possess a way of conveying more information in each message effectively than the current method.

2ND PREDICTION

Clearance interpretation will occur more quickly and accurately while using a graphic altitude situation display rather than using an ND with altitude in text on the ND and in the text clearance.

The study's results show distinct patterns in response time and contrasting patterns in percent correct answers when comparing hybrid formats that did use an ASD vs. ones that did not. After reviewing the response time, G+T and G+T+updUM showed similar response times across all elements (see figure 58 red and blue lines). This was expected because the primary difference between these two formats were only organizational and wording updates made to the SC-214 and SME.

Therefore the graphic conditions were nearly identical, resulting in similar response times. Figure 58 also shows hybrid formats using the ASD (green and purple lines); in all clearance categories response time was longer when communicating with hybrid formats containing the ASD. Additionally, pilot feedback regarding the ASD was not positive; the subjects mentioned that the altitude information displayed was too redundant and at times confusing. Table 45 indicates the significant differences between all hybrid formats. Human performance showed significant difference when comparing response time between hybrid formats with ASD vs. without ASD. A pattern is shown while using two, three, four, five, and six element clearances; this pattern suggests that the ASD delayed clearance interpretation time.

With respect to percent correct the results showed contrasting patterns. With regards to the two formats not using the ASD; G+T and G+T+updUM percent correct rates for clearances containing more than two UMs G+T+updUM allowed pilots to attain higher rates than G+T. As the number of elements increased G+T percent correct rates decreased while G+T+updUM percent correct rates were maintained above 86% for clearances containing more than two elements, see figure 60. The differences between these nearly identical formats are most probably due to the smaller subjects size in the G+T condition (n = 8) compared to the G+T+updUM (n=20). Formats containing the ASD show a clear difference in percent correct rates; text imbedded onto the graphic allows far better performance than G+T+ASD. It is likely the ASD was ignored for both formats based on subject comments. Contrary to response time there is no clear overall pattern that indicates a difference in percent correct rates when comparing formats using the ASD vs. ones that don't. However there is a peculiar occurrence in the data. Figure 59 shows a drastic drop in the percent correct rate for G+T when evaluating 4 element clearances. This drop in performance could be attributed to the issues that pilots were having with some of the UMs, such as offset to then rejoin at or before at or having the heading UM last in a clearance. The fewer number of subjects in this condition also results in more variance in the data.

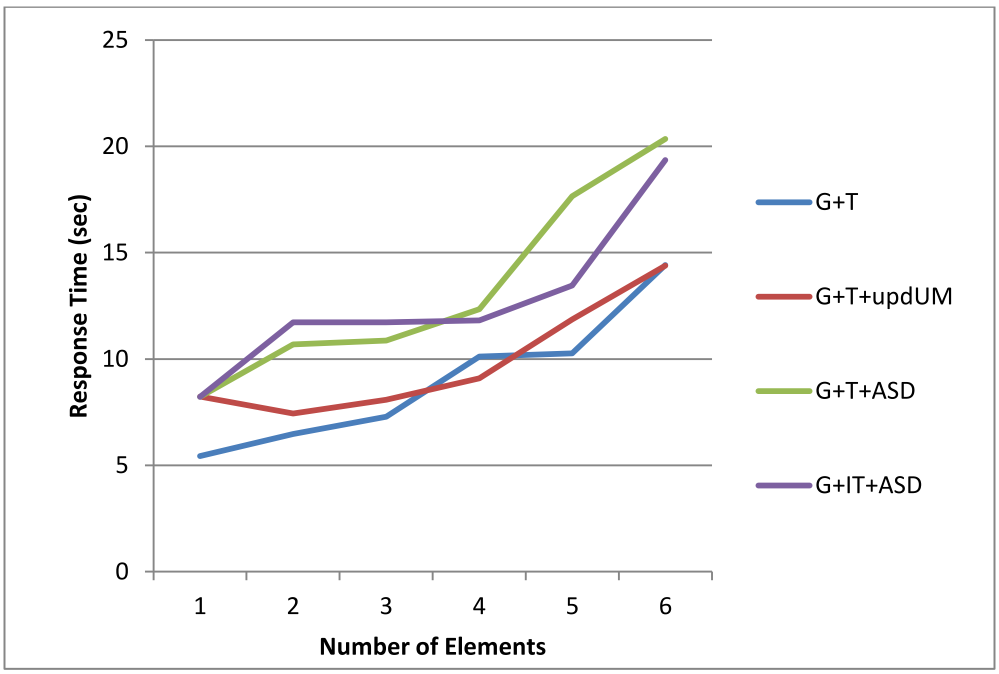


Figure 58 Graphics Comparison Response Time

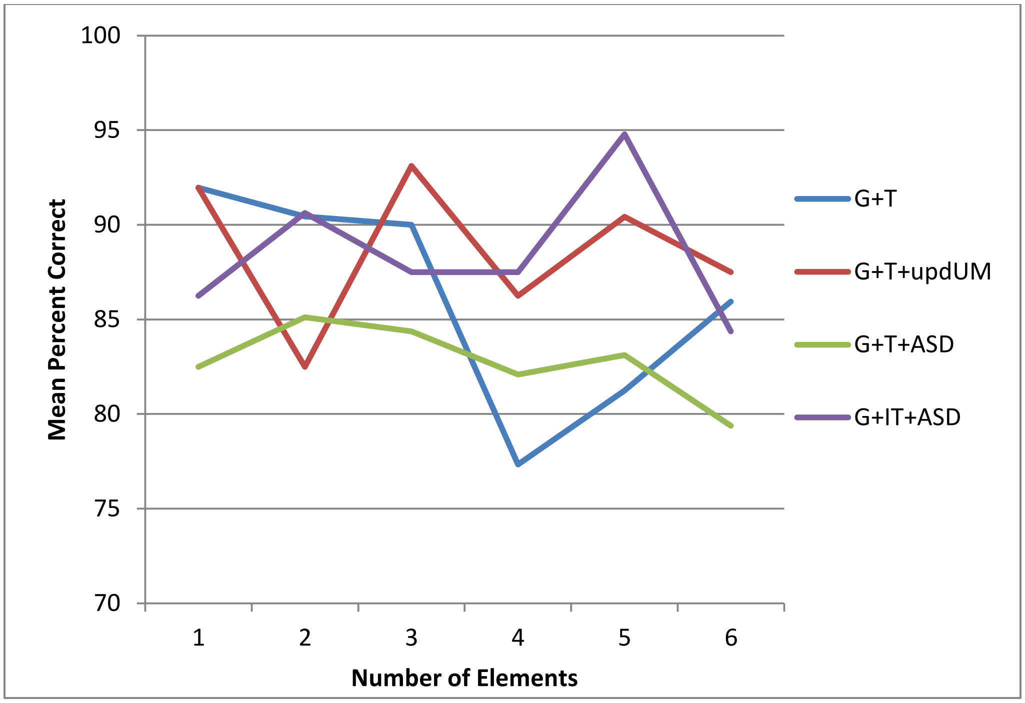


Figure 59 Graphics Performance Summary of Percent Correct

Table 45 Summary of Differences in Hybrid Formats

Summary of Differences in Hybrid Formats - with ASD vs. without ASD					
Letters indicate significant differences, Numbers are means					
Formats / Element	DV	G+T	G+T+updUM	G+T+ASD	G+IT+ASD
One	RT-s	B-5.44	A-8.24	A-8.22	N/A
	CA-%	A-91.9	A-82.5	A-86.3	N/A
Two	RT-s	A-6.47	A-7.45	B-10.68	B-11.72
	CA-%	A-90.44	A-82.5	A-85.1	A-90.63
Three	RT-s	B-7.28	B-8.08	A-10.87	N/A
	CA-%	B-90.0	B-93.1	A-84.38	N/A
Four	RT-s	AB-10.1	B-9.09	A-12.35	AB-11.8
	CA-%	A-77.34	A-86.25	A-82.08	A-87.5
Five	RT-s	B-10.23	B-11.87	A-17.66	AB-13.5
	CA-%	A-81.25	AB-90.4	A-83.13	B-94.79
Six	RT-s	A-14.42	A-14.49	B-20.35	AB-19.4
	CA-%	A-85.9	A-87.5	A-79.4	A-84.4
Nine	RT-s	A-8.53	A-12.59	N/A	N/A
	CA-%	A-68.75	A-68.75	N/A	N/A

3RD PREDICTION

Clearance interpretation will occur more quickly and accurately while using a hybrid of text imbedded in graphics rather than a hybrid of text and graphics. This prediction is based on the concept that the pilot will not be required to direct attention to the graphics and text separately.

The data shows patterns regarding the use of text imbedded in graphics. Regarding response time there are two observations. When clearances containing 2 elements are used for communication, response times are similar between G+T+ASD and G+IT+ASD. However, when using clearances with more than 3 elements the difference in response time becomes more apparent and marginally significant (see Table 45). The data suggests that text imbedded caused a positive effect on human performance when communicating longer clearances in comparison to G+T+ASD, resulting in shorter response times. However, due to the sample size and few UMs this trend in the data needs to be further investigated and tested in order to increase validation in this statement.

In regards to percent correct there was a clear distinction between formats Figure 59 illustrates the percent correct rates for G+T+ASD in the green line and G+IT+ASD in the purple line. The hybrid format using text imbedded allowed subjects to attain higher percent correct rates than G+T+ASD. Table 45 reinforces this trend by showing a significant difference when communicating with 4 element clearances.

4TH PREDICTION

Clearance interpretation time and accuracy will be the same for both correctly accepting a clearance and correctly rejecting a clearance.

The data revealed consistent patterns relating to response time and a mixed pattern relating to percent correct. Table 46 shows the significant differences in performance by format between subjects accepting vs. rejecting clearances. Regarding response time the results showed that with few exceptions (see Table 46) subjects were able to reject clearances in less time when using graphics as a communication format rather than text only. This difference becomes more apparent with greater separation in interpretation time as the number of elements increase within a clearance (4 and 5 element clearances). However with clearances containing over 5 elements the difference in interpretation time is not significant yet pilots still reject clearances in less time. Graphics allowed pilots to more quickly determine if a clearance had a error within context to therefore be rejected in less time and more accurately. It is also true that as the number of elements increases pilots were more conservative and tended to reject most clearances.

Table 46 shows the percent correct rates for responses. The data showed that in more cases, pilots correctly rejected clearances at a higher accuracy than correctly accepting clearances. Pilots mentioned that they were more “careful” when accepting a clearance rather than rejecting one. They explained that rejecting clearances is safer than accepting clearances.

Table 46 Summary of differences by format - Accept vs. Reject

Summary of Differences in Formats - accept responses vs. reject responses						
(*) indicate significant differences in response by format (+) indicates better performance while rejecting (-) indicates better performance while accepting						
Elements / Format	DV	Text	G+T	G+T+updUM	G+T+ASD	G+IT+ASD
One	RT-s	-	+	*+	*+	N/A
	CA-%	-	+	+	+	N/A
Two	RT-s	+	+	+	*+	*+
	CA-%	+	+	+	+	+
Three	RT-s	+	+	+	*+	N/A
	CA-%	+	-	-	+	N/A
Four	RT-s	-	*+	*+	*+	*+
	CA-%	+	+	+	+	+
Five	RT-s	-	*+	*+	*+	*+
	CA-%	*+	*+	*+	*+	-
Six	RT-s	+	+	+	+	-
	CA-%	+	+	+	+	+
Nine	RT-s	+	*+	*+	N/A	N/A
	CA-%	+	+	+	N/A	N/A

Additional Observations

The results also showed that as the number of elements in a clearance increase, there is an overall increase in intreprtation time regardless of format, this trend can be seen in Figures 56, 57, and 58. It is of course expected to take longer to interpret clearances that contain more information. Equally, there should also be a slight trend for errors to increase the amount of information in a clearance increases; Figure 59 shows G+T+ASD to be the only format that exhibits this pattern, other formats show a nonlinear trend.

From the subjective input there were two concerns that pilots consistently mentioned. Two clearance elements; REJOIN and HEADING brought confusion and ambiguity to the clearance. REJOIN AT OR BEFORE “location” was used as an element to concatenate clearances; pilots said that they did not know when to begin rejoining bringing uncertainty and ambiguity when making a decision. HEADING “degrees” if given to a pilot by itself or as the last element in a clearance it would bring uncertainty due to the lack of route closure. Pilots would not know how long or how far to fly the indicated heading. A reroute clearance needs to follow the HEADING element in a clearance to given clear indication as to how long or how far to fly the HEADING.

OBJECTIVES

The first objective of this research was to determine any differences in pilot performance when interpreting clearances of varying lengths and number of elements via DataComm displays using text-only versus a hybrid of text and graphic communication formats. The first prediction discusses the differences between clearance interpretation between text only and G+T; this discussion addresses the first objective. When graphics were used to present clearances interpretation time and accuracy are improved compared to text only when there are three or more elements in a clearance. The results are similarly to Hahn and Hansman’s (1992) work which showed improved decision making when graphics were included. The results from this study support Hahn and Hansman’s concept that hybrid formats of graphics and text are beneficial for interpreting clearances than a text only method.

The second objective was to determine whether different graphical formats affect the interpretability of uplink messages of varying lengths and content. The second and third predictions address this objective. The outcome in interpretation time and accuracy differed depending on the hybrid graphic format used for communication. Interpretation time was faster when using formats not containing the ASD. Percent correct rates were higher when imbedding text with graphics in the ND. The results indicate that ASD does not aid in clearance interpretation time ore accuracy. The text imbedded onto the ND graphic as a hybrid format showed improved accuracy in responses. However, due to the sample size and low number of UMs tested further investigation and testing is needed in order to increase validation in this statement.

The third objective was to identify any trends in performance or subjective pilot opinion concerning the relationships between the number of elements contained within a single clearance and the speed or accuracy of message interpretation. Predictions one through four discuss several trends in the objective data regarding performance depending on the number of elements contained in a clearance; as the number of elements in a clearance increase so did interpretation time. With respect to subjective opinions; pilots mentioned that the longer the clearance became the more useful the graphics were when interpreting clearances, pilots also suggested different graphics for specific elements. As an example pilots argued that placing a line across the display to replace the “rejoin” element of a clearance with “abeam” with the purpose of disambiguating the rejoin instruction.

In addition to number of elements, pilot subjective input revealed that clearance type caused an effect on interpretation time and accuracy. Pilots mentioned that clearances containing a “rejoin” instruction were difficult to process. The graphics design was not adequate. Based on these results the graphic was redesigned.

Similarly to Hahn and Hansman’s study in 1992 subjects stated that graphics were useful and important for clearance interpretation, with the exception of the ASD graphic for altitude. Pilots stated that the ASD was hardly useful and that the altitude information presented in the ND was sufficient to make a decision rendering the ASD redundant.

VII. RECOMMENDATIONS

As a part of a bigger effort to contribute to the NextGen program this study's results will bring insight to the use of graphics in ground-to-air communication. Based on the effects of hybrid text and graphic formats on human performance while interpreting clearances certain suggestions can be drawn. Tables 47 through 51 provide recommendations for considerations.

Table 47 Recommendation 1

Number 1	Number of Elements and The Use of Graphics
Title: Graphic Benefit Threshold	
Recommendation: Graphics are not needed while transmitting one element clearance messages.	
Rationale: As seen in the results when variations of graphics are coupled with text there is a positive effect on human performance while interpreting clearances in comparison to using text only. However, there is a point where graphics do not show this effect. When clearances contain one or two elements it is more efficient to communicate via text only. For example one element clearances are transmitted faster via text only. This type of clearance is more likely to be used as an immediate route change due to incoming traffic. However, not including graphics for one or two element clearances may cause confusion as to why the graphic is not included in these situations along with text.	

Table 48 Recommendation 2

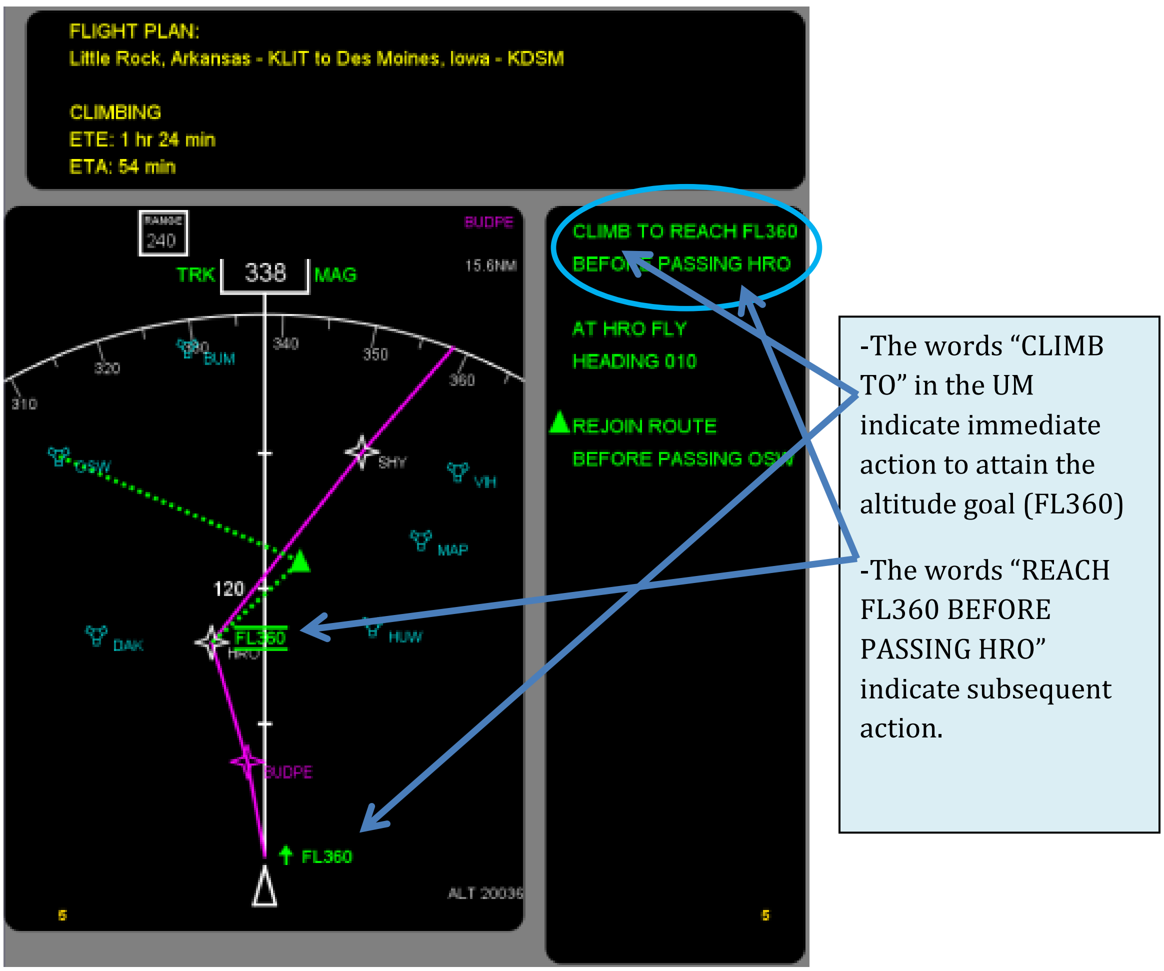
Number 2	Clearance Location to be Executed Immediately
Title: Immediate Clearance Graphics Location	
Recommendation: Locate graphics related to a clearance that requires immediately action beside the location status symbol representing the aircraft.	
Rationale: As the aircraft advances through its flight path, the pilot uses the ND display to determine the current location on the map by viewing the ownship triangle. The map moves around the ownship. When a clearance is executed immediately by the pilot it triggers an immediate change on the physical state of the plane and the map updates. For an ATC clearance a graphic symbol should be placed next to the white ownship to signal that the aircraft has reached a location to execute the transmitted clearance. 	

Table 49 Recommendation 3

Number 3	Graphics and Text Display Organization
Title: Coordinating Text with Graphics	
Recommendation: Apply graphics corresponding to text in the clearance message when text and graphics are presented separately. Use symbols or other design methods that illustrate and correspond to each clearance element.	
Rationale: When text and graphics are presented separately, there should be symbols or other design methods that illustrate and correspond to each clearance element. The design methods should follow the chronological order in which clearance elements should be executed by placing and coordinating graphics where needed. For example the text may have a symbol next to it that matches the symbol on the display. The text and graphics may have a coordinated number. The concept is to ensure that the pilot is able to reference the graphic and text provided where the message is displayed via graphics.	

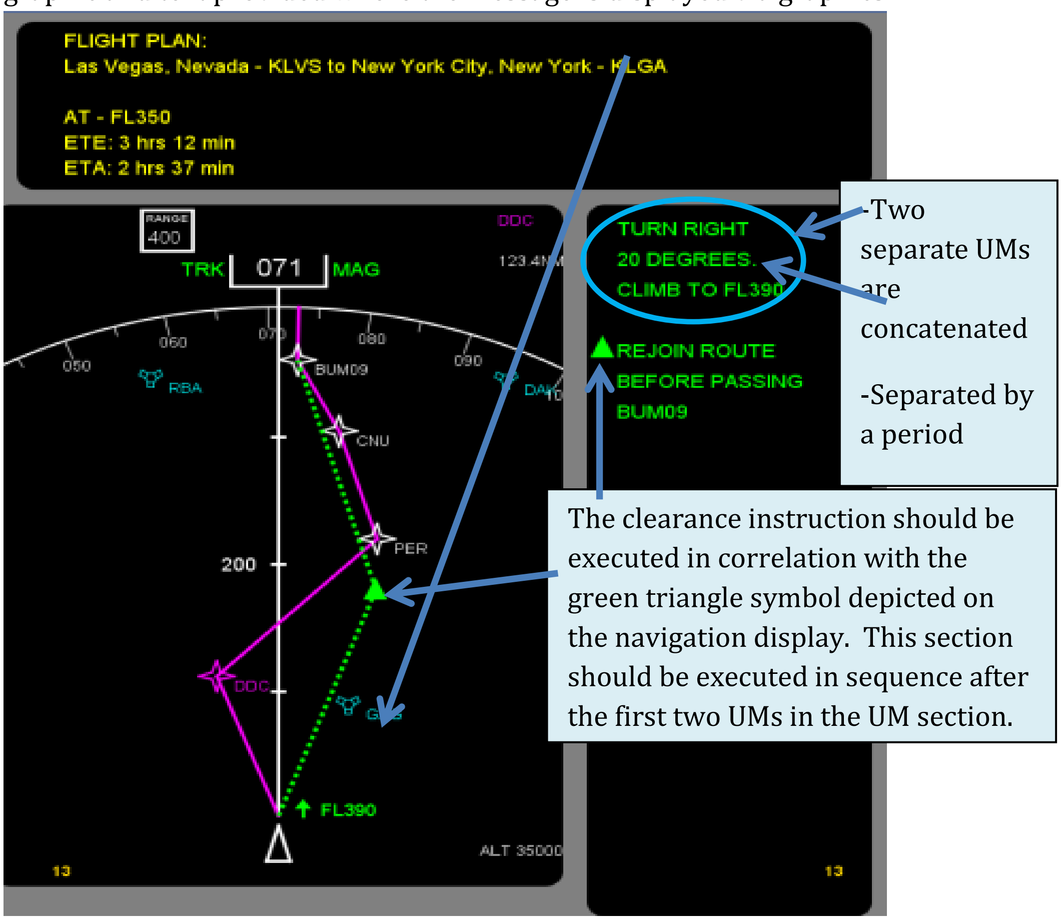


Table 50 Recommendation 4

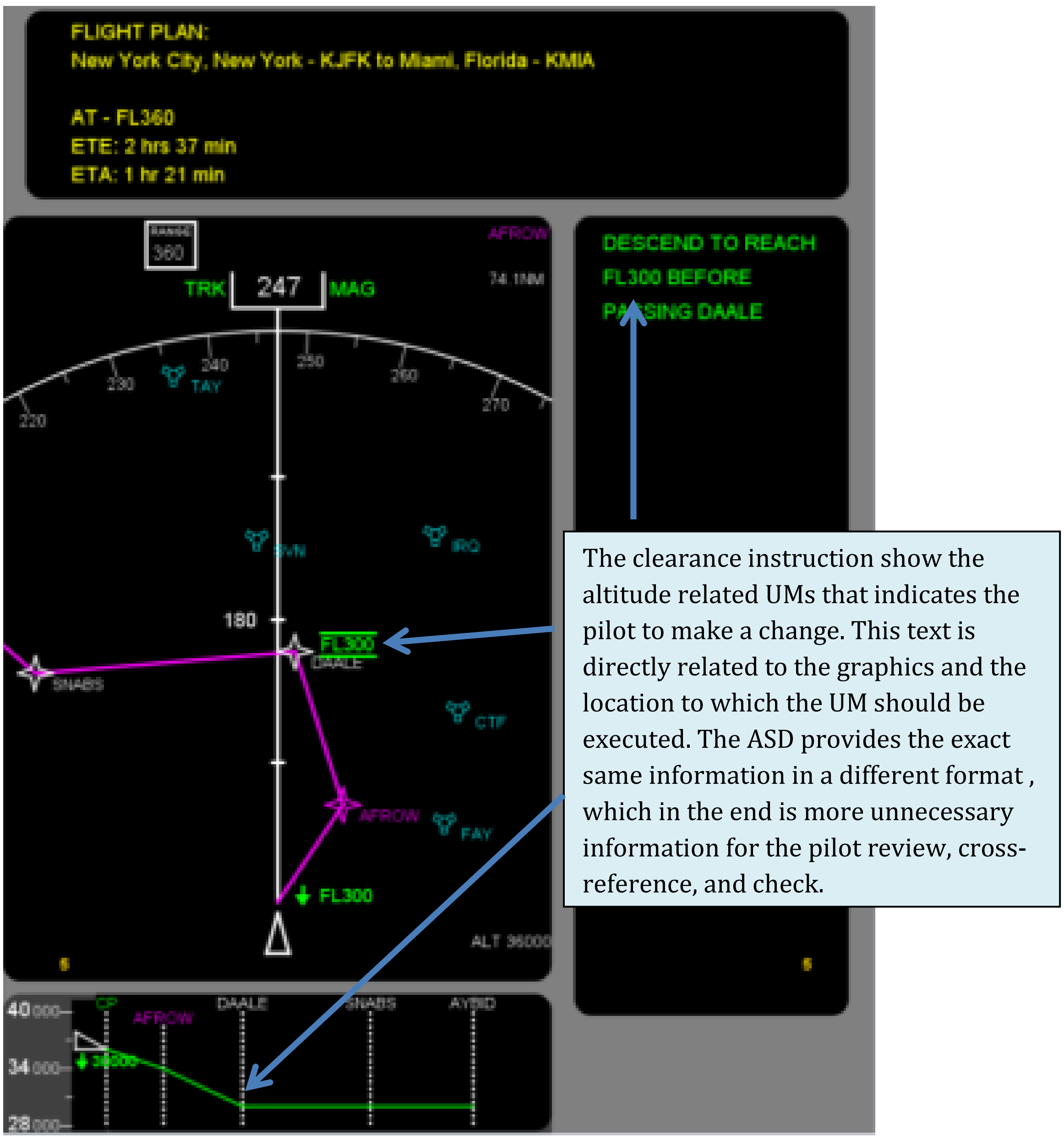
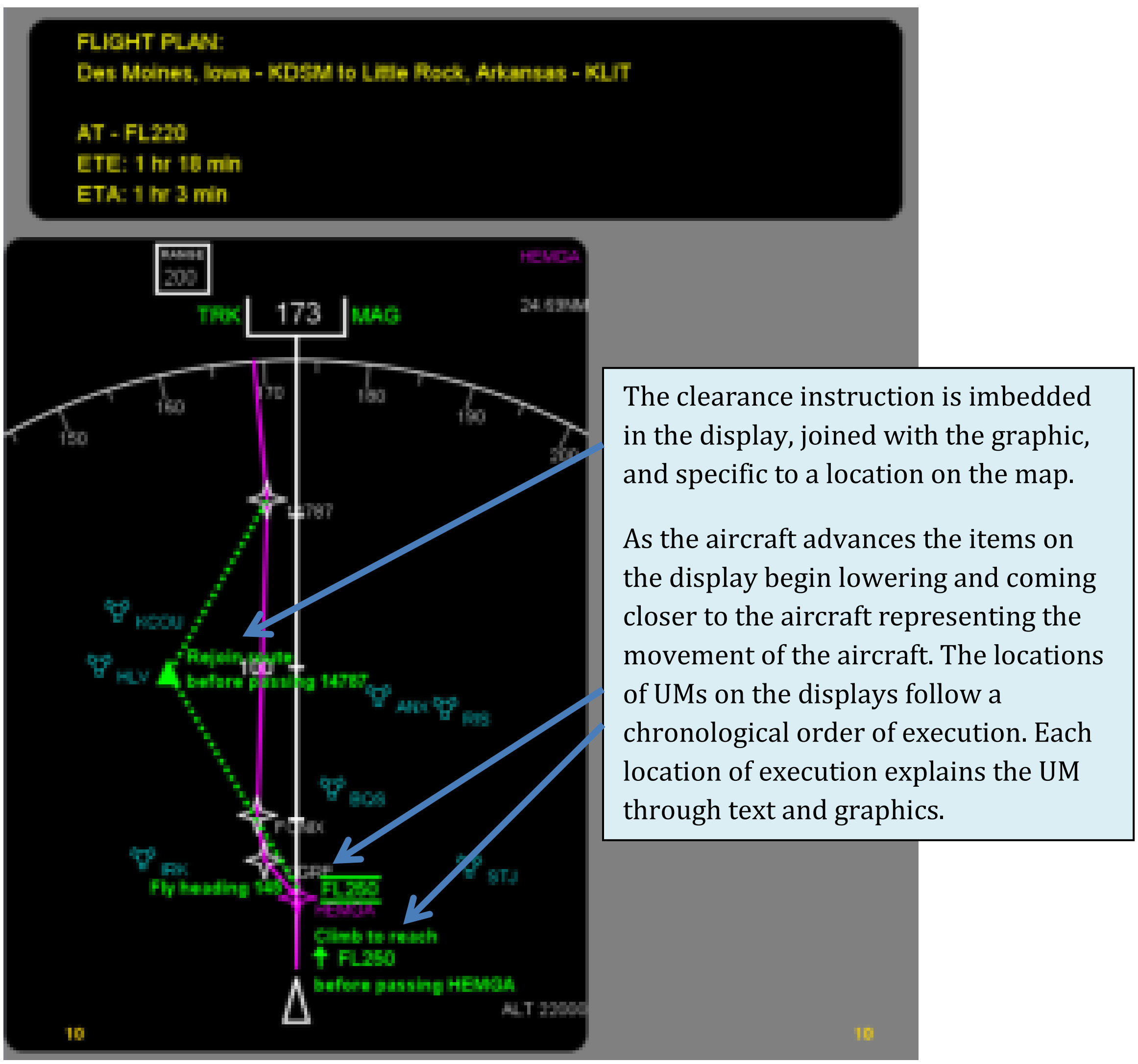
<table>
<tr><td>Number 4</td><td>Graphics and The ASD</td></tr>
<tr><td colspan="2">Title: Include altitude with text</td></tr>
<tr><td colspan="2">Recommendation: The graphics should include textual indication of altitude clearances.</td></tr>
<tr><td colspan="2">Rationale: The altitude situation display (ADS) did not provide useful information to pilots above and beyond what textual altitude information in the graphic provided.

</td></tr>
</table>

Table 51 Recommendation 5

<table>
<tr><td>Number 5</td><td>Text Imbedded in Graphics</td></tr>
<tr><td colspan="2">Title: Perform Testing for Text Imbedded in Graphics</td></tr>
<tr><td colspan="2">Recommendation: There was some evidence that the clearance text embedded directly into the graphic may improve performance. If this technique is to be used, human performance testing is necessary.</td></tr>
<tr><td colspan="2">Rationale: The results indicate that text imbedded had a positive effect on clearance interpretation with respect to the accuracy of pilot's responses; however, the evidence is limited based on sample size. Combining the text into and graphic may provide a more explicit way of chronologically displaying the clearance on the ND.

</td></tr>
</table>

VIII. FUTURE RESEARCH

The results of this research produced information necessary to aid the development of recommendations regarding communication formats that can be applied to DataComm. NexGen will need guidelines in order to design new communication systems; therefore questions regarding the use of graphics for clearance communication will arise. The observations were supported by both qualitative data collected during the experiment and quantitative statistical evidence that was gathered through DC-MAT. However in order create to robust set of design guidelines other questions and scenarios need to be considered.

This study was designed to test one pilot at a time which limits the interactions at the time the pilot interprets a clearance. There is a need for research investigating the interaction of a second flight deck crewmember with the pilot while performing air-to-ground communication with graphic formats. Additionally, this study used static scenarios without any simulated distractions from the real world. To further understand and investigate the interpretability of clearances, dynamic simulated scenarios incorporated into the experiments will allow more insight while testing. Pilots might perform tasks differently when presented with dynamic scenarios as well as communicating with a co-pilot while performing other primary tasks such as flying the aircraft.

Pilots mentioned during the question and answer session that not all clearances simulated accurate flying routines. Air traffic controllers hold the power to concatenate any elements existing in the SC-214 documents in any order that they choose. This broad range of options could lead to the concatenation of unusual clearances. A study that proposes the validation of the possible clearance combinations while concatenating messages would allow several questions to be answered. This type of validation analysis would be able to provide guidelines as to which combinations would not be desired while performing ground-to-air communication.

The graphics used in this experiment were simple geometric static figures. The limitations of this study's software did not allow for complex graphics; however the additions of the simple geometric static figures did show a positive effect on human performance while interpreting clearances. It would be interesting to see the effects of more advanced and sophisticated graphics similar to the studies conducted at NASA and summarized by Gallimore et. al. in 2011, but applied to the navigation display in a two-dimensional format. This would help answer questions regarding what type of graphics could be used for clearance interpretation.

While conducting this study there were several challenges. For future reference while conducting pilot studies, it is important to keep in mind that there are multiple levels of certification for pilots. Each one of those certifications separate and break down the possible pool of subjects making it difficult to recruit the required pilots with the required certification. Additionally, creating the proper cabin environment is essential in order to eliminate variation in the data. In this study while testing pilots, being in the same room with the subjects opened the opportunity for discussion. Although these conversations were very insightful, they also forced some data points to be discarded (outliers). However, when pilots are alone they may be less likely to provide verbal input. Marking down the clearances for discussion to be addressed at the end might result in less variation in the data. Finally, utilizing eye tracking devices while testing to determine where pilots gaze and for how long while viewing displayed information will shine some insight on questions regarding information prioritizing and display real estate.

IX. CONCLUSION

This study showed the effects text and hybrids of graphics-text on pilot performance using flight deck data displays. Pilot performance was positively affected by hybrids of graphics-text over a text only format while interpreting clearances. Hybrid communication formats generally allowed pilots to interpret clearance messages and respond in less time as well as more accurately than when using a text only format.

The flight deck data display used in this study (Navigation Display - ND) allowed the testing of hybrids formats through the use of simple graphics. This study used minimal graphics given the increased feasibility of graphic implementation in current aircraft systems. The ND is a common display on most commercial aircraft flight decks as an aid pilots in en-route navigation.

Different graphic-text hybrid formats were used to present clearances, and in general regardless of the technique, including graphics helped to support the interpretation time and accuracy for understanding clearances. When graphics were used to project future trajectory of the plane's path onto the ND, graphics retained the information on the display, allowing pilots to avoid continuously visualizing route path changes in comparison to the current flight plan and a text presentation of the clearance. The retained clearance information presented by the graphics on the ND allowed pilots to more efficiently use their cognitive abilities to analyze and evaluate the information.

This study was not able to include all the variables from the real world scenarios while testing ground-to-air clearance communication. The test was designed to be taken by a single pilot at a time and it tested the pilot's expertise and ability to make decisions based on static scenarios. Although the DC-MAT testing software was created to evaluate subject performance regarding clearance interpretation in a very simple environment, it has the potential to evaluate individual messages in a variety of graphic formats. The software used is customizable to suit different clearances under different scenarios. The DC-MAT is a tool that can be used during air certification and during design of flight deck displays by industry.

In the past the use of graphics has shown to enhance communication in busy environments (Wahlster et. Al, 1993). This study found that graphics enhanced interpretation of uplink clearances when compared to text regarding human performance. As the NexGen program progresses and new communication systems begin to develop, designers will need guidelines to create the parameters for many areas, one of them being flight deck displays. This study provided insight and support to build rules and guidelines for using graphics in clearance communication. As the transition from voice clearance communication evolves into digital satellite data communication, pilots will communicate through flight deck displays.

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Appendix A

Participant Instructions

The purpose of this study is to determine how ATC clearances, delivered as text & graphics rather than voice, affect pilots' abilities to understand and evaluate the clearances. To do this, we will be presenting you with several ATC clearances in text form that we want you to read and evaluate in the context of a specific flight situation. To begin the program, you will be required to press the "Enter" key to advance the screen. For each case, you will be presented with a brief flight plan and information about your current position and altitude' this information will be presented in text form and on a navigation display. You will review the flight plan and map display until you are familiar with where you are in the flight and where you are expected to go. Once you feel completely comfortable with your understanding of the flight plan, you will press the "Enter" key. An air traffic clearance will then be presented in text form and will appear to the right of your navigation display.

Your job will be to evaluate this clearance with respect to your flight plan and make a decision as to whether you should "Accept" the clearance or if you would "Reject" the clearance.

You should **ACCEPT** clearances that keep you on the planned route, OR, provide reasonable alternative paths to reach your destination, or a future waypoint along your route.

You should **REJECT** clearances that do not match the flight plan and route shown on the map display, OR, provide an impossible or unreasonable alternate route given your destination and phase of the flight. (In other words, if you would normally hesitate to execute a clearance and would contact ATC about its accuracy, then you should reject the clearance.)

To "Accept" a clearance you will hit the "1" key on your input device. To "Reject" a clearance you will hit the "3" key. You will also have the option to revisit the flight plan after you have moved onto the clearance; this button is designated as the "BS" button (Backspace) on the external keypad. Additionally, you will be able to manipulate the altitude situation display (ASD) by pressing the "0" key to display either the clearance or current ASD state. Once you select to either accept or reject the clearance, the simulator will ask you to "**DISCUSS**" any outstanding comments about the scenario (with the experimenter). You will then press "ENTER" to proceed.

We are asking that you treat these text clearances as you would when actually flying. When the message appears you should read and evaluate it as quickly and accurately as possible. You will repeat this procedure until the experiment is completed.

The experimenter cannot clarify any of the text messages or map displays during the experimental trials. If you have a concern about a particular trial, enter your response and **THEN** ask the experiment to note the trial number and your concern before the next trial. You will be given a break half way through the experiment. However, if you feel the need for a break before then, or at any time, just let the experimenter know.

- Do you have any questions?
- We will now start a few practice trials for you to get familiar with the procedure
  - Feel free to ask any questions during these practice trials.
- Do you have any questions?
- Now we will begin the experiment

Post-Experiment Questions

1. When evaluating the clearance message, were you more prone to study the graphics on the Navigation Display, or the text?

   ____
   ____
   ____
   ____

2. Was it hard to think in terms of flying a 737-800? Was the spec sheet useful? Was it realistic?

   ____
   ____
   ____
   ____

3. Did you find the graphics useful? And if you they were implemented as a standard, would you have a problem retraining to incorporate the technology?

   ____
   ____
   ____
   ____

4. Was the information about the scenarios enough for you to have sufficient **<u>situation awareness</u>** to make an accurate judgment on the clearance? If not what was missing?

   ____
   ____
   ____
   ____

5. Was the number inside the triangle useful? Did it confuse you at times? Should it be a “2” after an immediate clearance where a triangle is not needed?

   ____
   ____
   ____
   ____

6. Any comments, questions, additions…

____

____

____

____

Airplane Specs in Simulation (Boeing 737-800)

- Cruise Speed average of .73 Mach or 483 knots (8 mile/min)
    - Assume this average speed even on short flights

- Average plane weight 150,000 lbs.
    - Assume plane weight stays the same throughout the flight

- Descend rate
    - Maximum continuous descend 10,000 ft. (UNLESS APROACHING LANDING)
        - Anything less than that acceptable

- Ascend rate
    - Assume 250 knots below 10,000 ft.
    - Above 10,000 ft. assume Mach .73 (8 mile/min)
    - Maximum continuous climb 10,000 ft.
        - Anything less than that acceptable

- Takeoff to cruise altitude
    - 20 - 30 min

- Cruise altitude to landing
    - 20 – 30 min

WRIGHT STATE UNIVERSITY

INFORMED CONSENT FOR PARTICIPATION IN RESEARCH

Investigation of Baseline Performance For Understanding Text and Graphic-Based Aircraft Clearances

AGREEMENT TO PARTICIPATE

The purpose of this consent form is to provide me with the information to aid me in deciding whether or not I would like to be a part of this study. I am being asked to participate in this study, and I may ask questions about the purpose of the research, the possible risks and benefits, and anything else about the research or this form that is not clear. Once the research team has answered all of my questions, I can decide whether I would like to be in the study or not. This process is known as "informed consent." I will receive a copy of this form for my records if requested. This signed consent is to certify my willingness to participate in this observational research study.

PURPOSE OF RESEARCH

The purpose of this study is to determine the effects of text and graphic aircraft clearances on time to understand the clearance and percent corrects for pilot and non-pilot subjects. This study will provide data that will be used for input to design guidelines for the FAA. Future air flight will be using uplink and downlink data messages for clearances.

PROCEDURES

I will be asked to observe the screenshots of navigation scenarios. The number of screen shots will vary between 50 and 200. I will receive information about the current state of an aircraft in flight followed by an aircraft clearance message that will be presented as text or text with graphics. There will be three display sections on the simulator: the first one is the text based-simulated status of the flight scenario which you are given, the second one is Navigation Display which depicts own ship's navigating situations graphically, and the third one is a display to present textual clearance instruction. The clearance will vary from changes in one aircraft state up to and including sophisticated clearance information that includes heading, direction, altitude, and position. The composition of the presented clearances will vary. The researchers will explain the test program configuration and how to use the program.

During the trials I will be presented with the clearance information and asked to provide my response using a keypad based on my understanding of whether the clearance is acceptable given the state of the aircraft. After all the trials, I will be asked to answer a short questionnaire regarding my experience in the experiment. The experiment is expected to last from one to two and one-half (2.5) hours and I have the right to stop participating at any time. I will be told the approximate time given the number of trials (between 50 and 200) I will be asked to complete. During the trials my verbal feedback to the experimenter will be recorded using a digital audio recorded. No personal information will be included in the audio file. The file will later be converted to text and the audio file deleted by February 28, 2014.

RISKS, STRESS OR DISCOMFORT

There are no more than minimal risks for participating in this study. I will be asked to sit in one seat interpreting different messages that are provided. I will be given a rest break half way through the experiment. If I feel the need for a break I may inform the experimenter and will be given a short break.

BENEFITS OF THE STUDY

There is no direct benefit to me for participating in this study. However, this information will help researchers design guidelines and recommendations to improve safety in future air flight.

EXTENT OF ANONYMITY AND CONFIDENTIALITY

My private information will be treated as strictly confidential, and no one other than the researchers will know my identity. All completed documents including my private information will be kept in a locked laboratory in room 113 University Park, Building 3855 Colonel Glenn Hwy, Wright State University. My name will only appear on this informed consent. I will be assigned a subject number that will not be linked to the informed consent. That subject number is used during data collection on the computer, not my name. If email is used to set up appointment times, all emails will be removed from the computer after the experiment is completed and no later than one year after the experiment begins. Email will reside on a password protected computer.

CONTACT INFORMATION

Should I have any pertinent questions about this research or its conduct, I may contact:

Dr. Jennie Gallimore, the Principal Investigator jennie.gallimore@wright.edu	937-775-4096
Chang Geun Oh, Co-Investigator oh.4@wright.edu	937-919-4324
Steven Brent Kiss, Co-Investigator kiss.2@wright.edu	937-620-3607
Ricardo Munoz munoz.10@wright.edu	937-831-3136
Timothy Crory crory.2@wright.edu	978-697-4263
Pamela Tsang Pamela.Tsang@wright.edu	937-775-2469

If I have general questions about giving consent or my right as a research participant in this research study, I can call the Wright State University Institutional Review Board at 937-775-4462.

VOLUNTARY CONSENT

I am free to refuse to participate in this study or to withdraw at any time. My decision to participate or to not participate will not adversely affect my relationship with Wright State University or cause a loss of benefits to which I might otherwise be entitled.
My signature below means that I have freely agreed to participate in this investigational study.

____

Printed name of participant Signature of participant Date

____

Printed name of researcher Signature of researcher Date