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16. ABSTRACT As DataComm is a key enabling technology that significantly affects human performance, human factors experts have anticipated potential implementation challenges (Cardosi, Lennertz and Donahoe (2010). One significant issue is that DataComm equipment may not be integrated with flight management systems (FMS). The crew will be required to read the DataComm messages, interpret them, make decisions with respect to the flight, and then make the appropriate FMS input. There will be challenges for the flight crew even when DataComm and FMS flight deck systems are fully integrated. Current aircraft systems that have incorporated datalink to some extent have utilized text to provide clearances or messages from ATC to the pilot. Presenting spatial information to pilots via text only requires pilots to perform a mental transformation that can not only slow down the understanding of the messages, but also lead to interpretation errors. Thus, this research addressing presentation methods of ATC information received on the flight deck via DataComm is high priority. Volume 1 includes findings and recommendations for the flight deck user interface. Volume 2 describes the results of the studies and details the methods, results and discussion of each study. Experiment I investigated pilot performance using text uplink messages (UMs) concatenated into clearances versus a hybrid of graphics and text when evaluating ATC clearances. The results indicated that overall as the number of elements in a clearance increased the time required to interpret the clearance increased and errors increased. Hybrid conditions with graphics and text improved performance when there were 3 or more elements in a clearance. The results also indicated improvements in the number of correct responses when graphics are included. Experiments II and III evaluated pilot performance for responding to clearances and creation of downlink messages to ATC using two interfaces. Pilots were able to create requests more quickly and with greater accuracy when using the graphic-based drag and drop interface that automatically updated the text DM.			
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# **DataComm – Display Alternatives for the Flight Deck: Overview and Human Factors Recommendations Volume 2**

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**Prepared For FAA, NextGen Advanced Concepts and Technology  
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## Acronyms

ANOVA	Analysis of Variance
ASD	Altitude Situation Display
ATC	Air Traffic Control
ATP	Airline Transport Pilots
BS	backspace
DataComm	Datalink Communication
DC-MAT	Description of a Message Assessment Tool
DM	Downlink Message
FMS	Flight Management System
GraphicGen	Graphic Interface
HITL	Human-In-The-Loop
IDE	Integrated Development Environment
MCDU	Multipurpose (or Multi-function) Control Display Unit
MPC	Mean Percent Correct
MRT	Mean Response Time
ND	Navigation Display
NDB	Non-Directional Beacons
REML	Restricted Maximum Likelihood
RTCA	Radio Technical Commission for Aeronautics
SAS	Statistical Analysis Software
SC214	Special Committee 214
TextGen	Text Interface
UM	Uplink Message
VOR	Very high frequency Omni-directional Range
WILCO	Will Comply

**The FAA NextGen Human Factors Division (ANG-C1), coordinated the research requirement and its principal representative acquired, funded, and technically managed execution of the research services described in this report.**

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## **1. Executive Summary Volume 2**

Data communications (DataComm) is one of the Federal Aviation Administration's (FAA) key technologies supporting the transition to NextGen. DataComm refers to the communication between air traffic controllers (ATCs) and pilots which will change from voice clearances to satellite datalink communications. DataComm is a transformational program that is critical to the success of NextGen operations. It will provide infrastructure supporting other NextGen programs and operational improvements, and enable efficiencies not possible using air/ground voice communications alone.

DataComm will provide the following benefits:

- Improve controller and flight crew efficiency by providing automated information exchange
- Improve NAS capacity and reduces delays associated with congestion and weather
- Decrease congestion on voice channels and provides an alternative communications capability
- Reduce operational (and readback/hearback) errors associated with voice communications
- Provide a platform to enable future NextGen operations.

Because DataComm is a key enabling technology that significantly affects human performance, human factors experts have anticipated potential implementation challenges (Cardosi, Lennertz and Donahoe (2010). One significant issue is that DataComm equipment may not be integrated with flight management systems (FMS). The crew will be required to read the DataComm messages, interpret them, make decisions with respect to the flight, and then make the appropriate FMS input.

There will be challenges for the flight crew even when DataComm and FMS flight deck systems are fully integrated. For example, in Trajectory Based Operations (TBO), textual clearance displays that provide complex 4D trajectory information may be difficult for pilots to interpret in a timely and efficient manner without error. Current aircraft systems that have incorporated datalink to some extent have utilized text to provide clearances or messages from ATC to the pilot. TBO will require spatial understanding of the location of the aircraft with respect to location in 3D space as well as time. Presenting spatial information to pilots via text only requires pilots to perform a mental transformation that can not only slow down the understanding of the messages, but also lead to interpretation errors. Thus, research addressing presentation methods of ATC information received on the flight deck via DataComm is high priority.

To address this challenge, alternative flight deck displays with graphics, hybrid text and graphics, and other formats integrated with existing navigation displays or new DataComm displays may enable pilots to more easily identify, understand, and quickly respond to air traffic clearances and instructions. Alternative displays may also better support negotiation of clearances.

Supporting the FAA's Aircraft Certification Service need for regulatory guidance to evaluate alternative flight deck displays, research to develop human factors recommendations was conducted for such regulatory guidance concerning the minimum requirements for system characteristics and display of air traffic trajectory clearances on the flight deck. After a review of the existing literature on the subject, a series of human-in-the-loop (HITL) experiments were

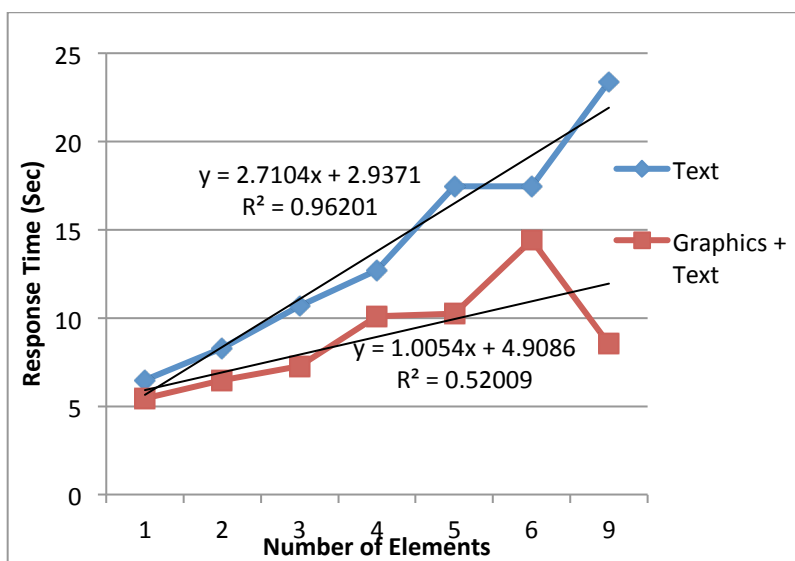
designed and conducted to evaluate human performance using text clearances and hybrid graphic and text clearances for uplink messages (UMs) to the flight deck and downlink messages (DMs) from the flight deck to ATC. Three experiments were conducted using different experimental paradigms. While it seems reasonable that graphics would provide pilots with information in a spatial format and would be easier to understand than text, a text condition was included in our studies to provide a baseline for comparison of the performance effects of graphics or hybrids of graphics and text as compared to text alone.

The products of this research were: 1) a set of specific human factors recommendations which are presented in Volume 1 Appendix 1, 2) a testing and evaluation tool called “Data Communications Message Assessment Tool” (DC-MAT), that supports the design as well as the rapid evaluation of graphic design concepts that are being considered for the flight deck (Vol 1, Appendix 2), and 3) information about issues with specific messages in the SC214 message set and concatenation of messages (Vol 1, Appendix 3) and 4) a dynamic flight simulation tool for evaluating human performance using different visual display formats, and input devices (Vol 2).

The results of this research program support development of regulatory guidance to address proposed new flight deck equipage that incorporates text displays of DataComm messages with graphical information in order to support timely and accurate pilot understanding of complex uplinked clearances and permit effective clearance negotiation with ATC.

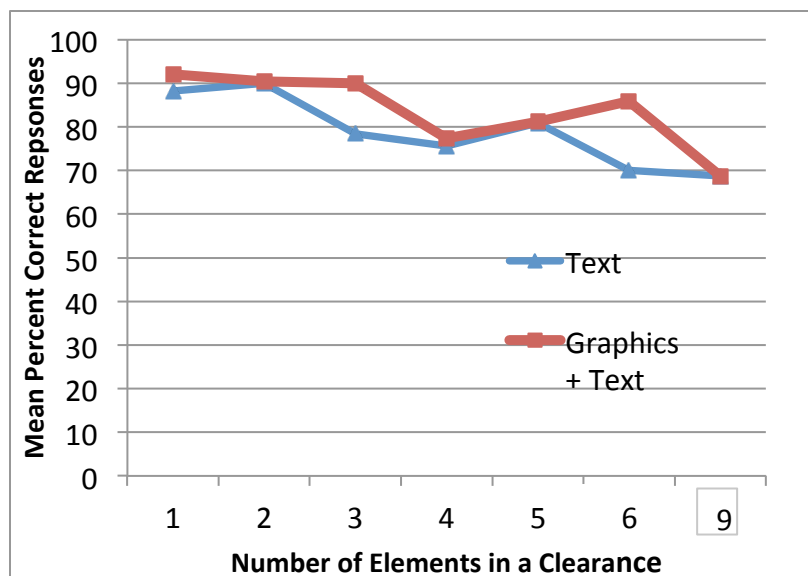
***The development of human factors recommendations to support human factors specialists in the FAA Aircraft Certification Service and Flight Standards Services is one of the major contributions of this research (Volume 1, Appendix 1).***

Volume 2 describes the results of the studies and details the methods, results and discussion of each study. Experiment I was designed to investigate pilot performance using text uplink messages (UMs) concatenated into clearances versus a hybrid of graphics and text when evaluating ATC clearances. The results indicated that overall as the number of elements in a clearance increased the time required to interpret the clearance increased and errors increased. Hybrid conditions with graphics and text improved performance when there were 3 or more elements in a clearance as illustrated in ExecSumFig 1.



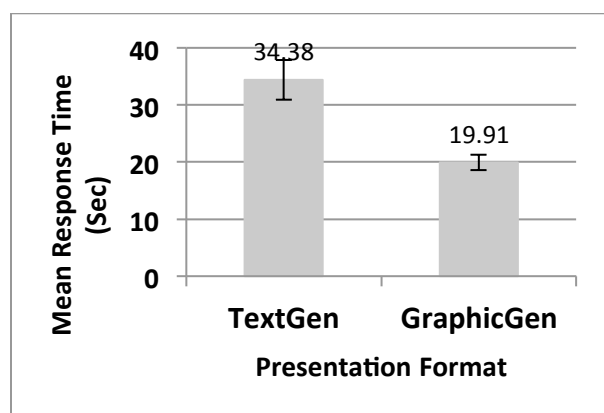
ExecSumFig 1. Mean Response Time (Sec) as a function of number of elements in a clearance.

The results also indicated improvements in the number of correct responses when graphics are included. ExecSumFig 2 illustrates the mean percentage of correct responses as the number of elements increase.

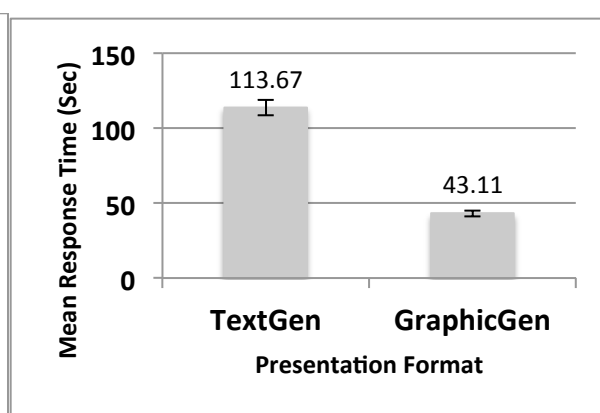


ExecSumFig 2. Mean percentage of correct responses to clearances as the number of elements increase.

Experiments II and III evaluated pilot performance for responding to clearances and creation of downlink messages to ATC using two interfaces. One interface, TextGen, used a text-based method as the primary input for creating DMs while GraphicGen used graphic manipulation. Responding to a clearance was improved using GraphicGen (Figure ExecSumFig 3). Pilots were able to create requests more quickly and with greater accuracy when using the graphic-based drag and drop interface that automatically updated the text DM as illustrated in Figure ExecSumFig 4.



ExecSumFig 3. Response time to correctly respond to a clearance for two conditions



ExecSumFig 4. Response time to create a DM using text versus graphic manipulation

There continues to be a need for future research. Specific considerations are to evaluate the graphic techniques in a full simulation environment under nominal and off-nominal flight

conditions. There is a need to evaluate the usefulness of the recommendations, and additional recommendations are likely needed. One area of continued research is graphic display of time information on the flight deck to support not only DataComm but also complex TBOs.



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## **2. Introduction and Overview**

The **objective** of this project was to research and develop human factors recommendations that will help to define minimum flight crew interface requirements for depicting graphical clearance data for near to midterm implementation of air-ground Air Traffic Control (ATC) Data Communications (DataComm). The purpose of these recommendations will be to assist human factors specialists in the FAA Aircraft Certification Service and Flight Standards Service to perform assessments of the acceptability of text and graphical flight deck display formats used in equipment and software for display of simple and complex DataComm messages.

Volume 1 provides 1) a brief overview of the two-year research project, 2) the human factors recommendations for the use of graphics in DataComm, 3) a description of a message assessment tool (DC-MAT) developed and used in the first experiments, and 4) information about specific SC-214 messages. A literature review was delivered in a previous technical document and is not repeated in either Volume 1 or 2 in order to reduce report size.




Volume 2 provides descriptions of human-in-the-loop simulation method and results from which many of the human factors recommendations were derived.

Volume 2 is sectioned as follows: Section 2 is a brief overview and research assumptions. Section 3 describes Experiment I conducted using the DC-MAT tool focusing on human performance for interpreting text versus graphics and text hybrid for UMs that were concatenated into clearances. Section 4 describes Experiment II, which provided an interface for pilots to send requests to ATC using DMs. Section 4 describes Experiment III evaluating two different graphic interfaces for interpreting UMs and creating DMs.

### **2.1. Exploratory Research**

In order to obtain as much information as possible over the two year time span, several exploratory experiments were conducted. Figure 1 presents an overview of the three simulations. For experiment I we developed the static paradigm called the Data Comm-Message Assessment Tool (DC-MAT) and began by evaluating the baseline condition of TEXT only for clearance interpretability. Clearances were created using the RTCA SC-214 Data Comm Message Set. UMs were concatenated to create clearances. While these data were collected we continued to build the graphics into DC-MAT. As graphics were added, additional pilots participated using graphic and text hybrid formats. As Experiment I was underway a portable dynamic simulator was developed to provide assessment of human performance for both UM and DM concatenated messages. This simulation allowed pilots to respond to clearances and negotiate a clearance by sending requests to ATC during en-route flight. Cockpit primary flight displays and alternative DataComm displays updated in real time.



Experiment I	Experiment II	Experiment III
<p>Simulation Type: DC-MAT (Static)</p> 	<p>Simulation Type: Dynamic Sim Interface: TextGen</p> 	<p>Simulation Type: Dynamic Sim Interface: GraphicGen</p> 
<p><b>Conditions</b></p> <p>Five presentation formats Text &amp; Hybrid clearances SC-214 UMs # of elements in a UM</p>	<p><b>Conditions</b></p> <p>Hybrid clearances. Pilot creates DM using text input, buttons and virtual keyboard. Graphic of DM is created during DM creation. Concatenation of DMs.</p>	<p><b>Conditions</b></p> <p>Hybrid clearances. Pilot creates DM using graphic manipulation. Graphic of DM is created during DM creation. Concatenation of DMs.</p>
<p><b>Dependent Variables</b></p> <p>Mean response time to interpret % correct responses for Accepting a clearance Rejecting a clearance Pilot feedback</p>	<p><b>Measured Performance</b></p> <p>Mean response time to interpret Mean response time to create a DM % correct responses for Accepting a clearance Rejecting a clearance Pilot feedback</p>	<p><b>Dependent Variables</b></p> <p>Mean response time to create a DM % correct responses for Accepting a clearance Rejecting a clearance Pilot feedback</p>
<p><b>Findings</b></p> <p>Hybrid text + graphic faster more accurate than text. Pilots indicate they need graphics for DataComm.</p>	<p><b>Findings</b></p> <p>Interface technique reduces need to type entire DM. Pilots need graphic when creating DMs.</p>	<p><b>Findings</b></p> <p>Graphic manipulation faster than textual button presses used in TextGen. Pilots prefer Graphic manipulation.</p>

**Figure 1. Overview of the Three Simulations.**

## 2.2. Research Assumptions

There are a large number of variables that can affect pilot performance using DataComm. Research assumptions are listed below.

1. Mixed aircraft data link equipage.
2. Some upgraded technology and use of ground technology.
3. Integrated DataComm messages can be provided in MCDU for review and then directly loaded into FMS.
4. Ability to access trial flight plans.
5. Ground automation elements will have the ability to coordinate trajectories, and set time constraints over a single waypoint.
6. Departure and approach optimization tools will feed trajectory formulation process.

In addition to the assumptions described above the research was limited in scope to evaluate text and graphic + text formats for DataComm during the en route phase of flight. The research focused on clearances that affect an aircraft's current or future trajectory (e.g. speed, heading, altitude, route, clearances and restrictions). UMs/DMs or instructions that do not affect the flight route were not evaluated (e.g. transfer of communications, contact/monitor, or report requests).

There are many complicated factors that can affect human performance related to DataComm. As with any study it is not possible to take into consideration every issue. In Experiment I the number of elements in a clearance was investigated. Generally, as the number of elements increase we expect response time to increase; however, the increase in time is not necessarily linear. The inclusion of number of elements (through concatenation) is one definition of complexity. The results related to number of elements provided by including this variable provided trend information.

Another consideration is the creation of flight scenarios. The scenarios influence performance. Many different scenarios were created. As lessons were learned with respect to scenario realism, unrealistic scenarios were identified and eliminated. However, this research did not explicitly control for scenarios.

Each UM and DM are unique and how they might be concatenated is also unique. It was not the purpose of this research to evaluate specific UMs or DMs or their concatenation with respect to human performance.

The research used part-task HITL simulation. The specific data values of time to respond and errors are under conditions where one pilot is focusing all their attention on DataComm. Two-crew scenarios were not included. Although the rich data provides a means for creating minimum graphic requirements, additional research would be necessary to evaluate performance under full task conditions.

The selection of a criterion level of message complexity at which a particular display format will be acceptable is a decision that will need to be studied. We did not attempt to address this point.

### **3. Experiment 1: Interpretation of Text and Hybrid Graphics and Text Formats of UM Clearances for DataComm**

#### **3.1. Method Experiment I. Text versus Graphics Using Concatenated UMs**

##### **3.1.1. Objectives**

The objective of this experiment was to determine human performance differences, measured by time to interpret a clearance and percent correct responses, when clearances were presented as text compared to different graphic formats. The basic research question is whether graphics will improve human performance when using DataComm. Considering that most clearance information presented to pilots is spatial in nature (where is the aircraft in 3D space and time in relation to ground, traffic, and weather?) the use of text alone requires the pilot to cognitively transform the text information into spatial information. If the information is presented as spatial information, the need for the cognitive transformation may be eliminated, improving performance.

##### **3.1.2. Hypotheses**

While the expectation is that graphics will improve performance, it is possible that graphic designs could hinder performance, therefore the null hypotheses were stated as two tail tests:

- 1) There is no difference in mean response time to interpret a clearance between TEXT and Graphics + Text
- 2) There is no significant difference in mean response time among the four hybrid graphic presentation formats.
- 3) There is no significant difference in percent correct interpretation between TEXT and Graphics + Text.
- 4) There is no significant difference in mean percent correct interpretation among the four graphic presentation formats.

##### **3.1.3. Experimental Design**

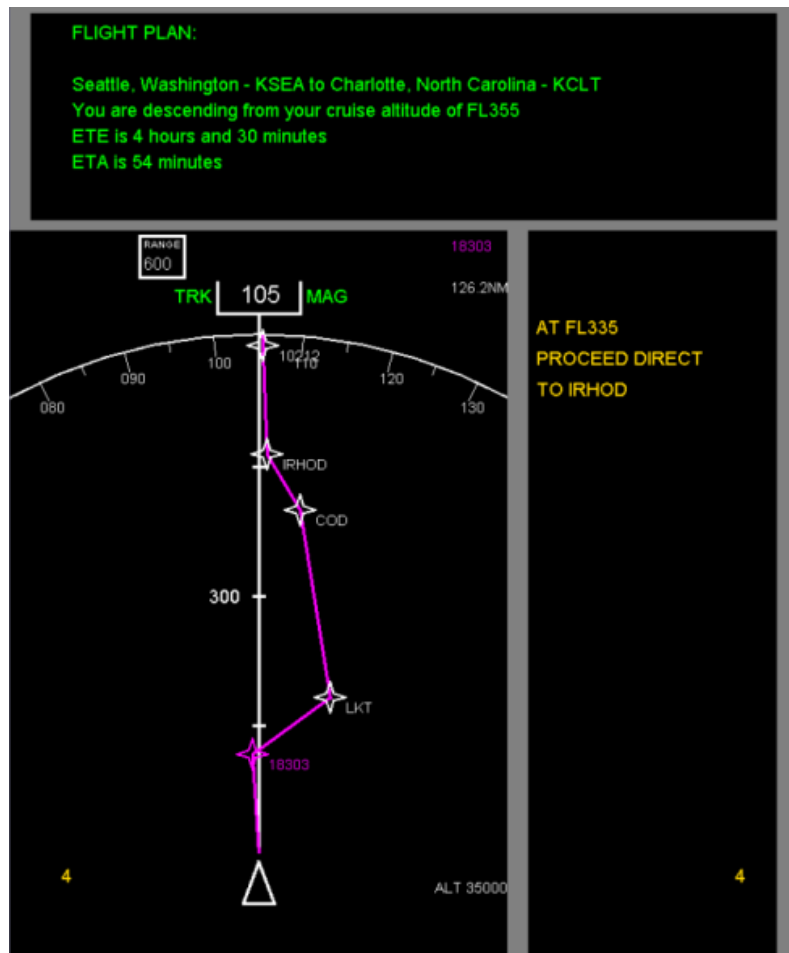
The experimental design was between-subjects with one independent variable, presentation FORMAT, with five levels. The five levels are described in the next section. A control variable was also included; the number of elements in a UM clearance. The number of elements included 1, 2, 3, 4, 5, 6 and 9. It was not feasible to create a factorial design with number of elements as a variable because the specific concatenated UMs were different depending on the number of elements. However, this variable allows us to analyze the data at each level of clearance, and to examine performance trends as the number of elements increase.

##### **3.1.4. Independent Variables**

###### **3.1.4.1. Baseline text only (Text)**

The clearances were presented to the pilot as TEXT to the right of a navigation display (ND). Figure 2 illustrates a screen shot showing the ND with the current flight path, and the TEXT

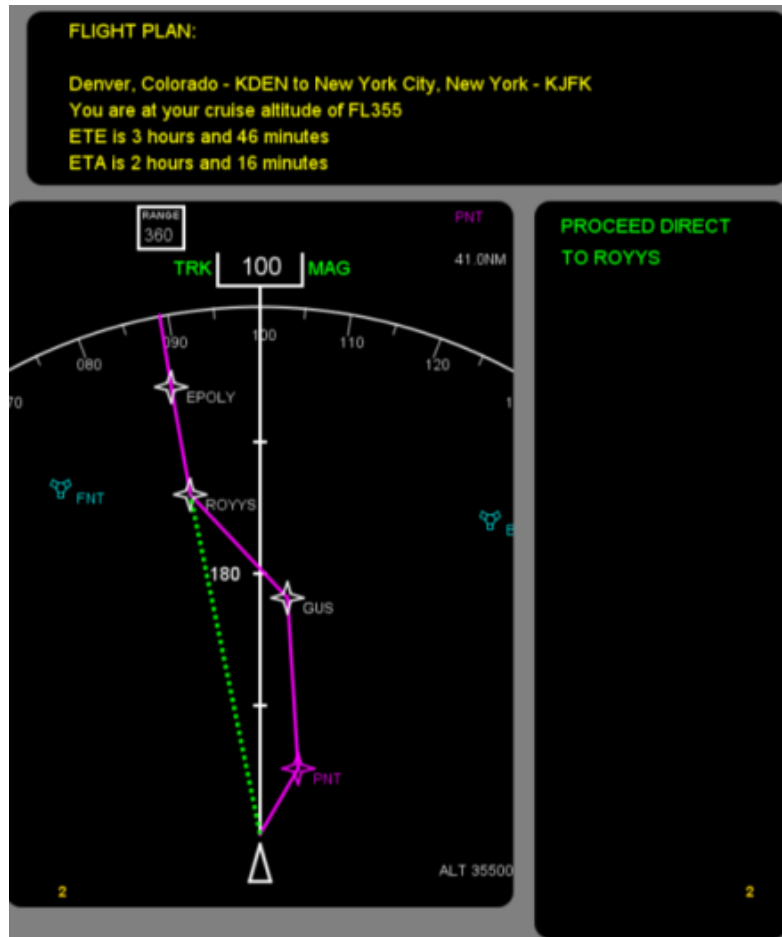
clearance on the right. The flight plan is illustrated at the top. (Please see Volume I for a full description of this experimental tool, DC-MAT).



**Figure 2. TEXT Format. The Magenta Line Shows Current Flight Path.**

#### **3.1.4.2. Graphics + Text (G+T)**

The Graphics +Text (G+T) format included the TEXT clearance in the same location to the right of the ND as the Text condition. A graphic representation of the clearance was drawn on the ND as illustrated in Figure 3. (Specific meanings of graphic symbols are described in Section 3.1.9, Stimuli Graphic Symbols). The graphics were placed on the ND at the location that the action or clearance should be executed along the route. Figure 3 illustrates an example of a graphic “Proceed Direct to POSITION” clearance.



**Figure 3. G+T Format. Green Dotted Line Shows UM Graphic, Proceed Direct to ROYYS.**

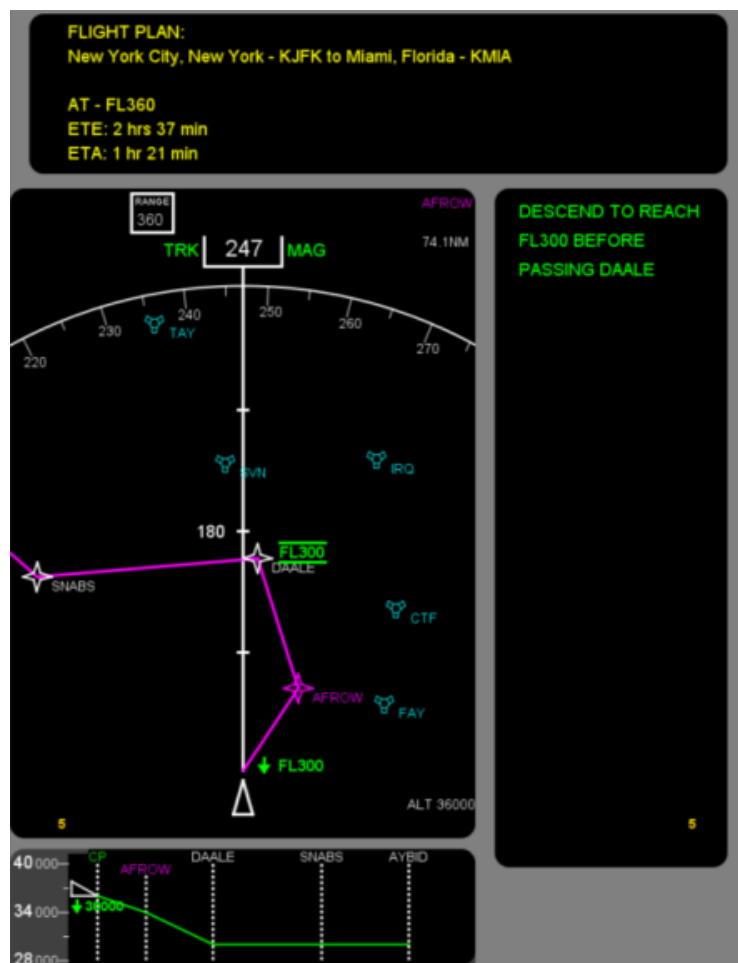
#### **3.1.4.3. Graphics + Text updated UM wording (G + T + updUM)**

This format is nearly identical to G+T. After completing a set of subjects with the G+T format several changes were made to the SC-214 messages. We consulted with three SC214 experts to discuss UMs. Based on their input, the original 40 clearances (See table 1 under Clearances) used for the conditions of TEXT and G+T were restructured. Specifically five UMs were modified (see Table 2), and one was deleted from the scenarios (MAINTAIN [level]). If the UM was in a concatenated clearance it was updated in the concatenation as well. A few clearances were also reworded (see Table 3). It was expected that these updates would not affect performance. The condition is still G+T. However, to control for possible variation, the condition of G+T was run again and was called G+T + updated UM (G+T+updUM). All other graphic formats, except G+T, use updated UMs.

#### **3.1.4.4. Graphics + Text with Altitude Situation Display (G +T + ASD)**

This format included adding an Altitude Situation Display (ASD) under the ND to provide specific information within a clearance related to altitude. Figure 3 illustrates this FORMAT. The ASD provides altitude on the left, an arrow indicating direction, and a green line illustrating

the altitude across waypoints, which are listed at the top of the ASD. Pilots could switch between the clearance graphic (green line) and current state (magenta line).



**Figure 4. G+T+ASD Format**

#### **3.1.4.5. Graphics with Imbedded Text with ASD (G + IT + ASD)**

The TEXT was removed from the right window of the display and integrated into the ND. The ASD was also present for this FORMAT. Figure 4 illustrates a concatenated re-route clearance.



Figure 5. G+IT+ASD Format

### 3.1.5. Clearances

Table 1 lists the 40 clearances, UM numbers, and number of elements used for Text and G+T FORMATS. The number of subjects for each FORMAT is listed under the format. As previously discussed, the first test was the baseline condition of TEXT using 40 clearances and 10 subjects. This was followed by G+T with 8 subjects. MAINTAIN [Level] was dropped for the G+T condition. The asterisk indicates which clearance was used for the format.

Table 2 lists the five UMs that were modified and Table 3 lists clearance that were restructured. All modified UMs were used for all subsequent clearances. As new FORMATS were tested, UMs with more than one element were used, as these are more likely to require graphic formats for better human performance. There was a limit to the time and number of subjects available which also required the use of fewer subjects and fewer UMs as the research progressed.

**Table 1. Clearances and Number of Subjects for Text and G+T.**

SC-214 Clearance			FORMAT Number of Subjects Tested	
	UM Number	Elements	Text N = 10	G+T N =8
MAINTAIN [level].	UM19	One	*	DROPPED
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	*	*



SC-214 Clearance			FORMAT Number of Subjects Tested	
	UM Number	Elements	Text N = 10	G+T N =8
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 [position].	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	*	*

SC-214 Clearance			FORMAT Number of Subjects Tested	
	UM Number	Elements	Text N = 10	G+T N = 8
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 OR BEFORE [position].	UM27, UM97, UM68	Five	*	*
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	*	*

**Table 2. SC-214 UM changes.**

<b>UM Number</b>	<b>Old UM</b>	<b>Update to...</b>	<b>New UM</b>
UM68	REJOIN ROUTE AT OR BEFORE [position]	. . . Was updated in the SC-214 Message Set to become . . .	REJOIN ROUTE BEFORE PASSING [position]
UM22	AT [position] CLIMB TO [level]	. . . Was updated in the SC-214 Message Set to become . . .	AFTER PASSING [position] CLIMB TO [level]
UM25	AT [position] DESCEND TO [level]	. . . Was updated in the SC-214 Message Set to become . . .	AFTER PASSING [position] DESCEND TO [level]
UM27	CLIMB TO REACH [level] AT OR BEFORE [position]	. . . Was updated in the SC-214 Message Set to become . . .	CLIMB TO REACH [level] BEFORE PASSING [position]
UM29	DESCEND TO REACH [level] AT OR BEFORE [position]	. . . Was updated in the SC-214 Message Set to become . . .	DESCEND TO REACH [level] BEFORE PASSING [position]

**Table 3. Clearances for Graphic Formats (restructured).**

Updated Clearances			FORMAT		
Clearance Text	UM Number	Number of Elements	G+T+updUM N=20	G+T+ASD N=20	G+IT+ASD N=20
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	*	*	
CLIMB TO REACH [level] BEFORE PASSING [position].	UM27	Two	*	*	*
DESCEND TO REACH [level] BEFORE PASSING [position].	UM29	Two	*	*	*
AT [level] PROCEED DIRECT TO [position].	UM78			*	*
AT [level] EXPECT DIRECT TO [position].	UM 90			*	*
CLEARED TO [position] VIA [route clearance enhanced].	UM79				*
CROSS [position] AT [level].	UM46			*	
CROSS [position] AT OR ABOVE [level]	UM47			*	
CROSS [position] AT AND MAINTAIN	UM49			*	

Updated Clearances			FORMAT		
Clearance Text	UM Number	Number of Elements	G+T+updUM N=20	G+T+ASD N=20	G+IT+ASD N=20
[level].					
FLY HEADING [degrees]. DESCEND TO [level]	UM190, UM23	Two	*	*	
FLY HEADING [degrees]. CLIMB TO [level]	UM190, UM20	Two	*	*	
TURN [direction] HEADING [degrees]. DESCEND TO [level]	UM94, UM23	Three	*	*	
CLIMB TO [level]. FLY HEADING [degrees]. PROCEED DIRECT TO [position].	UM20,UM190, UM74	Three	*	*	
FLY HEADING [degrees]. CLIMB TO [level]. AT [level] PROCEED DIRECT TO [position].	UM190, UM20, UM78	Four		*	
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 [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 BEFORE PASSING [position].	UM65, UM68	Four	*		*

Updated Clearances			FORMAT		
Clearance Text	UM Number	Number of Elements	G+T+updUM N=20	G+T+ASD N=20	G+IT+ASD N=20
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, UM 339	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 [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced]. AT [position] CLEARED TO [position] VIA [route clearance enhanced].	UM339, UM 339, UM339	Nine	*		

### **3.1.6. Dependent Variables**

Pilot performance was measured with two dependent variables: response time to interpret the clearance and mean percent correct response. Each clearance was replicated four times. Two clearances were designed into scenarios to be correct and pilots were expected to ACCEPT the clearance based on instructions provided at the beginning of the testing. Two clearances were incorrect and pilots were expected to REJECT the clearance. Therefore the dependent variable for mean percent correct includes 1) mean percent correct accepts, and 2) mean percent correct rejects.

### **3.1.7. Subjects**

Pilots were recruited from the Dayton region and an aircraft company in the United States. Pilots were screened for a minimum of 100 flight hours. A total of 66 pilots were tested across the various formats. Not all pilots saw all formats. Each pilot participated in two formats maximum. Pilot average age was 43.4 years. The average number of flight hours was 5,926. Ninety-seven and one-half percent (97.5%) of the pilots held an instrument rating. Ninety percent (90%) were male. The pilots were recruited from different backgrounds; 75% had commercial flight background, 15% had general/private aviation background, and 10% had military background.

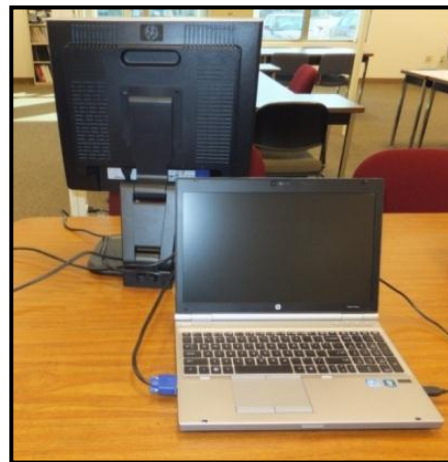
### **3.1.8. Apparatus**

#### **3.1.8.1. 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. Figures 6, 7, and 8 illustrate the hardware.



**Figure 6. Pilot's View of the DC-MAT Simulator.**



**Figure 7. Experimenter's View of the DC-MAT Simulator.**



**Figure 8. External Keypad.**

### **3.1.8.2. Software**

The software was custom designed and developed using JAVA programming 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 created, DataComm Message Assessment Tool (DC-MAT), is described in a subsequent section below and in Volume I, DC-MAT.

### **3.1.9. Stimuli: Graphic Symbols**

The graphics were basic geometric figures and lines. The following figures illustrate and describe the graphics and their meaning. Not all the graphics were used in every scenario. That is, only graphics relevant to the clearance were used.

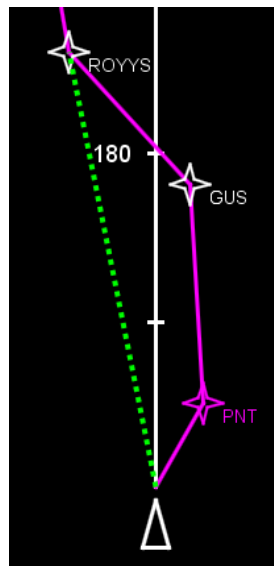
Figure 9 Green Triangle: Indicated when to begin the execution of a clearance at a specific location. Numbers inside a triangle: Indicated chronological order of clearances when two or more concatenated clearances were used as a sequence.



**Figure 9. Green Triangle with Number.**

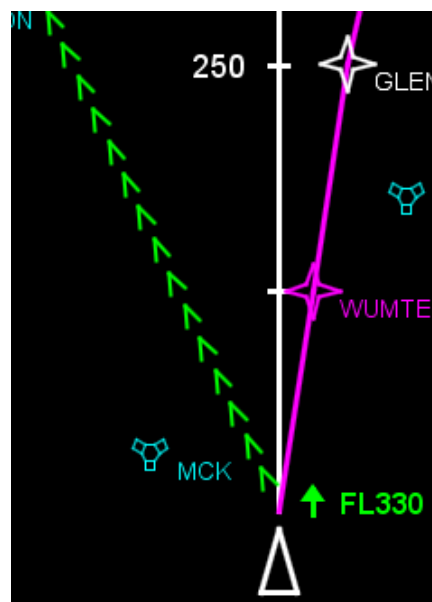


Figure 10 Green dotted line: The green dotted line depicted an alternate path given a re-route clearance. The magenta solid line is the original or current path.



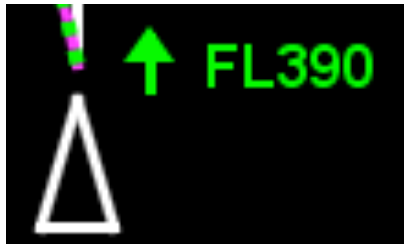
**Figure 10. Green Dashed Line for New Path and Magenta Current Path.**

Figure 11 Green carat line: Illustrated the specific heading direction of a clearance. It does NOT show an alternative re-route path.



**Figure 11. Heading Carat Line.**

Figure 12 White triangle: The white triangle indicated the aircraft current position. Text placed next to current position indicated immediate execution of a clearance.



**Figure 12. Current Aircraft Position (White Triangle) and Symbol to Indicate Immediate Execution.**

Figure 13 Altitude Text: Indicated the altitude related to the clearance.



**Figure 13 Graphics + Text Altitude Element.**

Figure 14 Arrow next to text: Illustrated the direction (climb/descend) of an altitude change.



**Figure 14 Arrow - Altitude Change and Direction.**

Figure 15 Line below altitude text: Indicated to reach and stay above the altitude. A line above the altitude text indicated to reach and stay below the altitude.



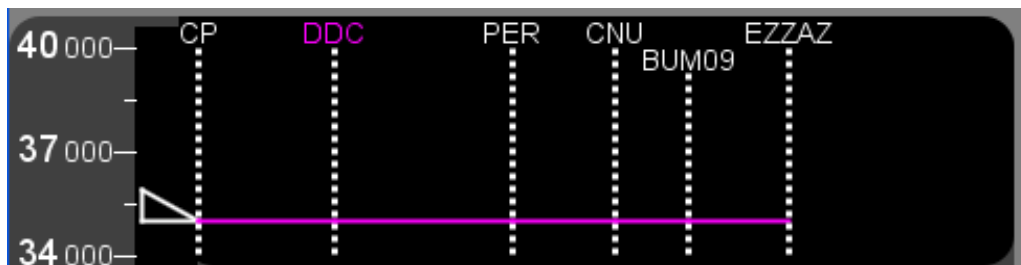
**Figure 15 Solid Line Below the Altitude.**

Figure 16. Line above and below: Indicated to reach and stay at the altitude.

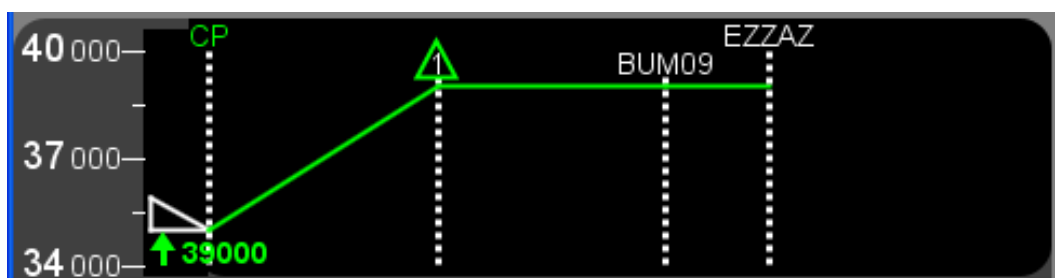


**Figure 16 Solid Lines Above and Below the Altitude.**

Figure 17 and 18 illustrate the Altitude Situation Display (ASD) for the current state (magenta line) and the cleared state (green line). Each ASD illustrated the next waypoint along the route at the top of the graph. The arrow next to the altitude number indicated direction of climb, while the number itself indicated the target altitude.

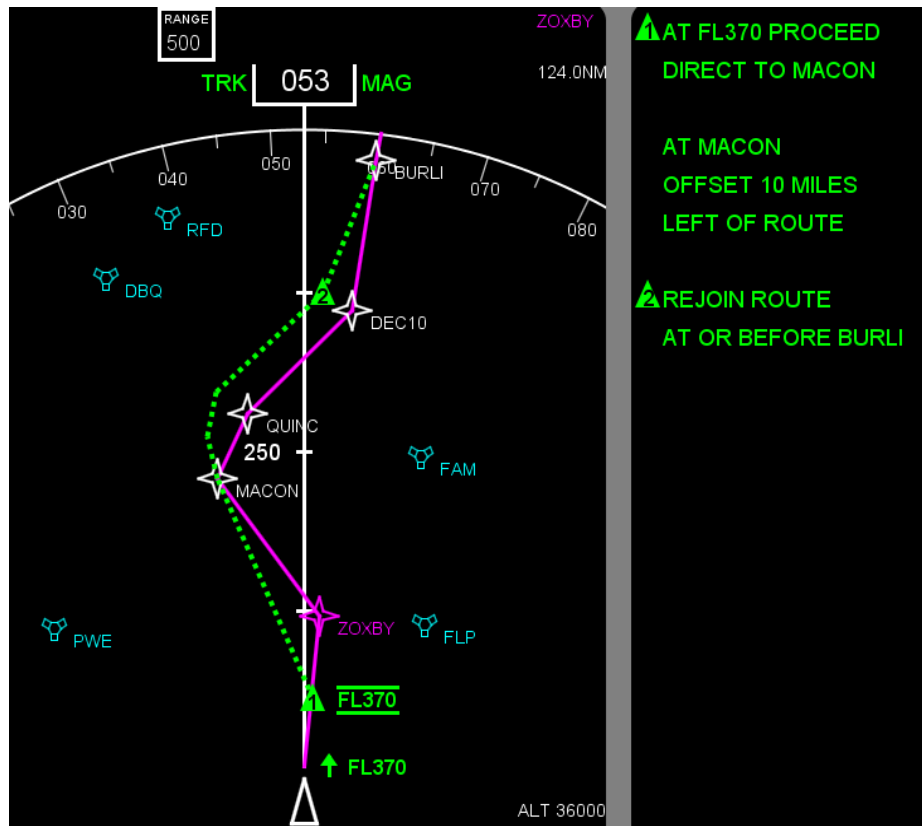


**Figure 17. Current Flight Path Altitude.**



**Figure 18. Cleared Flight Path Altitude.**

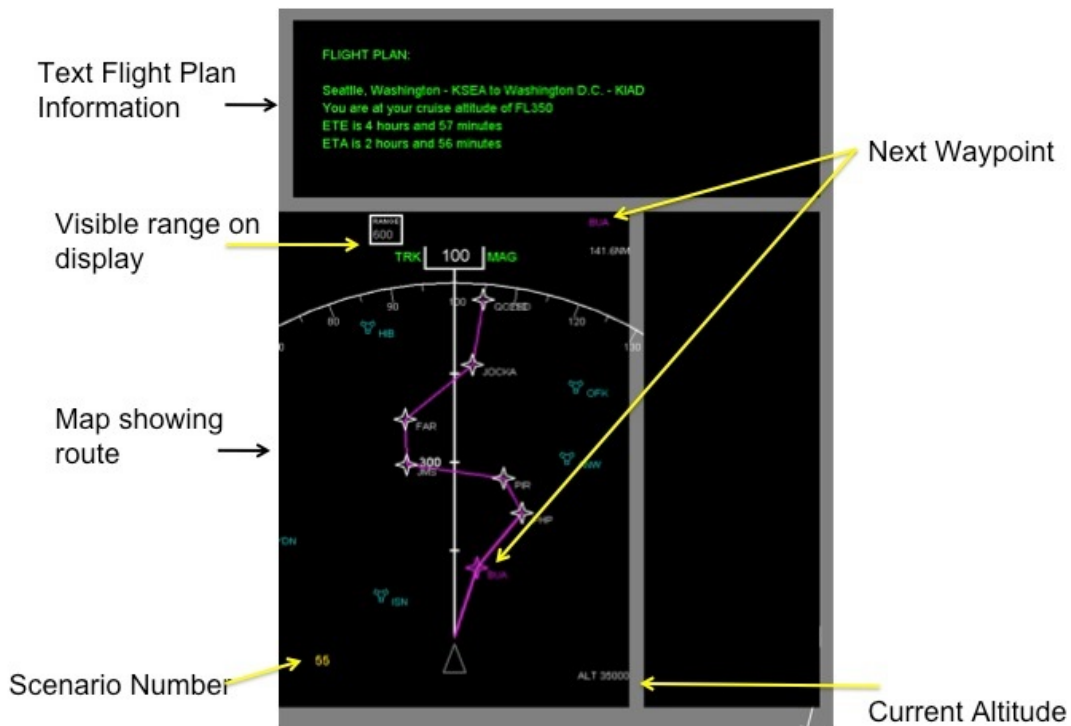
Figure 19 illustrates a scenario with concatenated UMs requiring sequential actions by the pilot.



**Figure 19. Example Scenario With Concatenated UMs.**

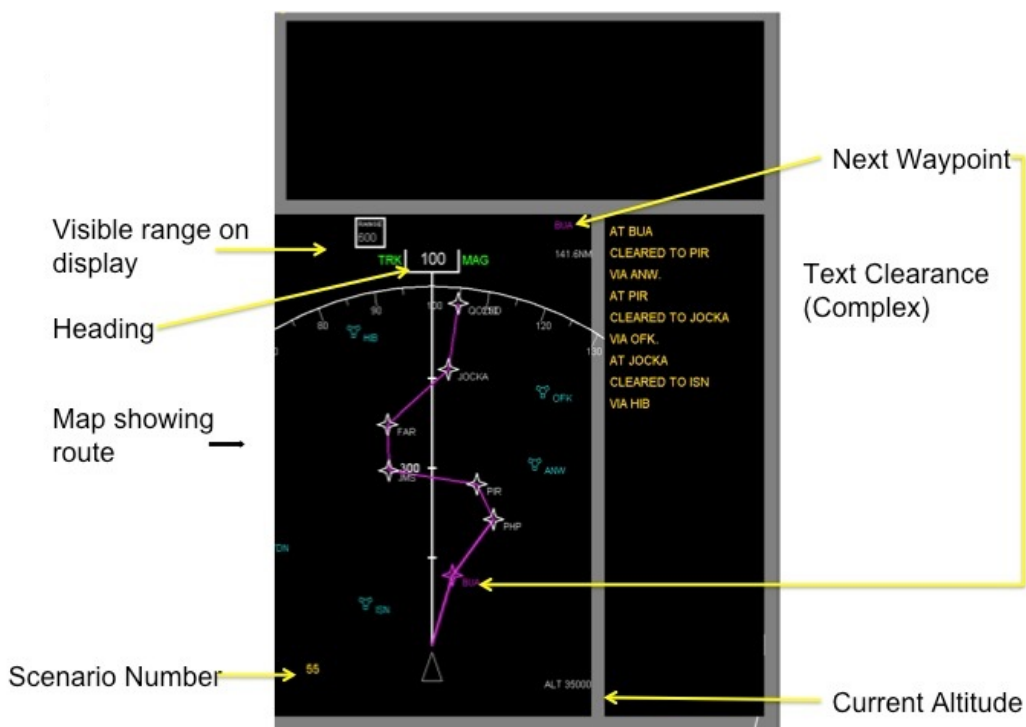
### **3.1.10. DataComm Message Assessment Tool (DC-MAT)**

A method was designed to evaluate the interpretation of clearances by measuring pilot time to interpret a clearance (response time) and the percentage of correct responses. 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 correct, and to obtain feedback from pilots concerning the interpretability of clearances. The goal was to provide a methodology for independently evaluating DataComm UMs. The method focused on uplink clearances that affect an aircraft's current or future trajectory (e.g. speed, heading, altitude, and route). This methodology is 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 in a box on the top of the screen. This information was provided to the pilot first to give situational awareness about the scenario. The left box is the emulated ND from a Boeing 777; the amount of information provided in this display was enough for subjects to make a decision. The graphics to depict a clearance were drawn on the ND. Figure 20 illustrates the screen the pilot reviewed prior to a clearance to obtain situation awareness about the scenario.



**Figure 20. Situation Awareness information Displayed Prior to Clearance.**

After reviewing the scenario the pilot pressed 'Enter' on the keypad and the clearance was displayed in the box on the right of the screen as illustrated in Figure 21.



**Figure 21. Text Clearance Information.**

### **3.1.11. Experimental Procedure**

The pilot sat in front of the screen with a small keyboard input device. The pilot pressed the 'Enter' key when they were ready to evaluate the current flight situation and a timer was started. The pilot 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. The clearance was displayed, the flight plan text was removed, and the response timer was started. Pilots had the option of displaying the flight plan again by pressing the backspace (BS) button. Under graphic conditions the clearance was displayed on the ND. After reviewing the clearance, the pilot 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 pilot through the flight plan, navigation display, UM text and when relevant the ASD. To view the current and cleared information on the ASD, the pilot toggled back and forth between the two states using the "0" number key.

The protocol called for removing the textual flight plan information after the pilot indicated they understood. The feature of allowing them to press a button to bring the flight plan back was added with the intention of providing textual reference of their original route which is available in current aircraft via maps or other options. Those scenarios in which the pilot brought back the flight plan were noted in the data file.

The pilot 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 led them to the same destination or future waypoint on the original plan. The pilot rejected the clearance if it did not match the flight plan or sent them on a path that did not lead to their destination. In addition the subject would reject 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 require flying to a waypoint already passed, or to a waypoint off the flight plan and 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. Pilots 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 in the negative (reject).

Upon completion of all trials those scenarios the pilot noted as confusing were discussed. Qualitative data were collected this way; providing a better understanding of their perceptions and difficulties related to scenarios or clearances.

### **3.1.12. Results**

#### **3.1.12.1. Data Overview – Description and Manipulation**

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 format, TEXT, G+T, etc. RESPONSE refers to whether the correct 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 whether the pilots correctly accepted or rejected clearances based on FORMAT type. A separate analysis was conducted at each level of number of elements. 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. Significant interactions were analyzed using simple effect F-tests.

Outliers were identified in the response time data. Outliers occurred when pilots would talk about the scenario before responding with an Accept or Reject. These instances were noted during the experiment and the outliers were removed. The number of outliers was 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 for normality. The ANOVA and post-hoc test values are listed in Appendix A.

### 3.1.13. One Element Clearances

Table 4 lists the 8 one element clearances and formats tested.. (Note one element clearances were not tested in the FORMAT G+IT+ASD).

**Table 4. One Element Clearances and Format Tested.**

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	*	*		

### 3.1.13.1. Mean Response Time (MRT) One Element

The two main effects (RESPONSE and FORMAT) were statistically significant as well as the interaction (FORMAT\*RESPONSE). The interaction is illustrated in Figure 22. The asterisk (\*) in the figure indicates significant differences after performing the simple-effects F-test. The FORMATS G+T+updUM and G+T+ASD resulted in significant differences in response time depending on whether the pilots were correctly accepting versus correctly rejecting a clearance. In both cases, response time was slower when they were accepting a clearance. The interaction indicates there are no differences in MRT based on RESPONSE type for the other formats. However, it must be noted that for the G+T+updUM one UM was used (4 clearances). The G+T+ASD is based on two UMs (8 clearances) that are different from the one tested with G+T+updUM. Therefore, what can be taken from this analysis is that for one-element UMs there was no real difference in performance between TEXT and G+T.

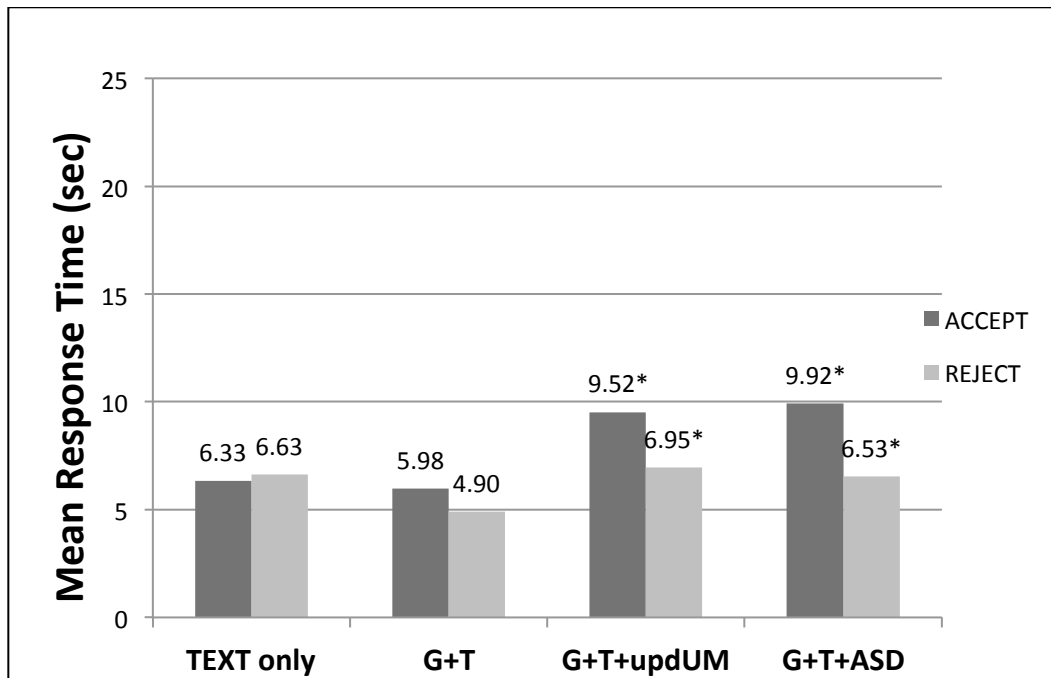
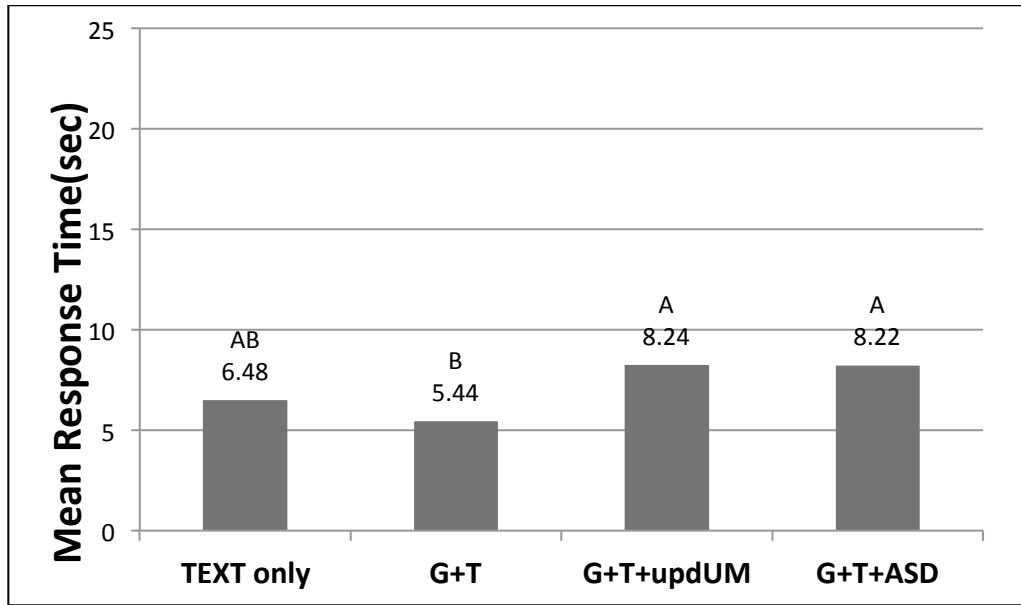


Figure 22. One Element MRT for the FORMAT by Response Interaction.

The main effect of FORMAT illustrated in Figure 23 confirms that for one element clearances there is no difference in MRT for TEXT vs. G+T. In Figure 23 there are letters at the top of each bar that indicate if there was a significant difference. Different letters indicate a significant difference. The differences for G+T+ updUM is based on the fact that it was a rejoin clearance, which many pilots had difficulty with. The higher MRT for G+T+ASD is based on the need to evaluate two separate displays. This difference is discussed in the Discussion Section.





**Figure 23. One Element MRT as a Function of FORMAT.**

With respect to MRT for the main effect RESPONSE, correctly accepting a clearance took longer ( $X = 7.94$  sec) than correctly rejecting a clearance ( $X = 6.25$ ).

### 3.1.13.2. Mean Percent Correct (MPC) One Element

For one element clearances there were no significant effects for MPC.

### 3.1.14. Two Element Clearances

Table 5 lists the seventeen two element clearances evaluated and the formats tested.

**Table 5. Two Element Clearances and Format Tested.**

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	UM88	*	*			

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
[position]						
TURN [direction] [degrees] DEGREES	UM215	*	*			
CLEARED TO [position] VIA [route clearance enhanced]	UM79	*	*			*
AT [position] CLEARED [route clearance]	UM83	*	*			
CROSS [position] AT [level]	UM46	*	*		*	
CROSS [position] AT OR 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	*	*	*	*	

#### 3.1.14.1. Mean Response Time Two Element

The two main effects RESPONSE ( $p = \leq 0.0001$ ) and FORMAT ( $p = \leq 0.0001$ ) and the interaction FORMAT\*RESPONSE ( $p = 0.0044$ ) were statistically significant. Figure 24 illustrates the interaction.

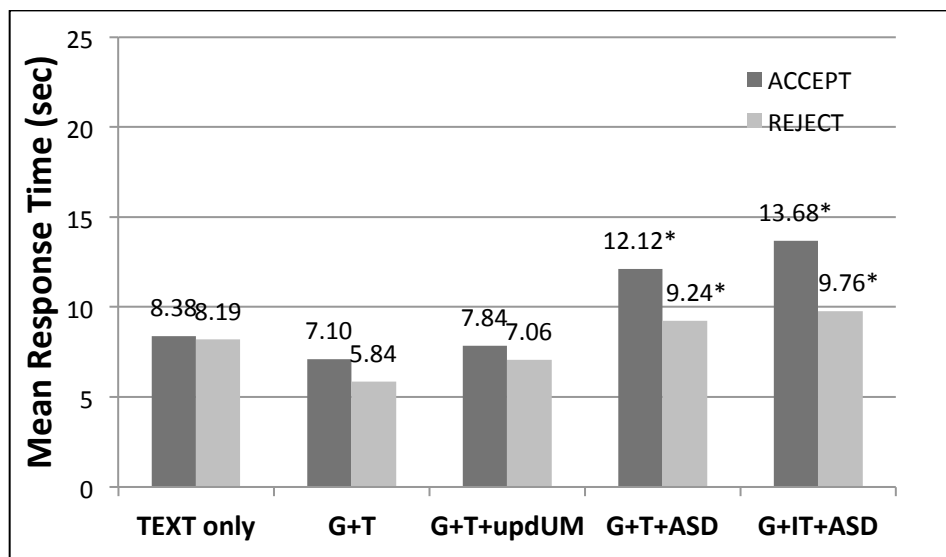
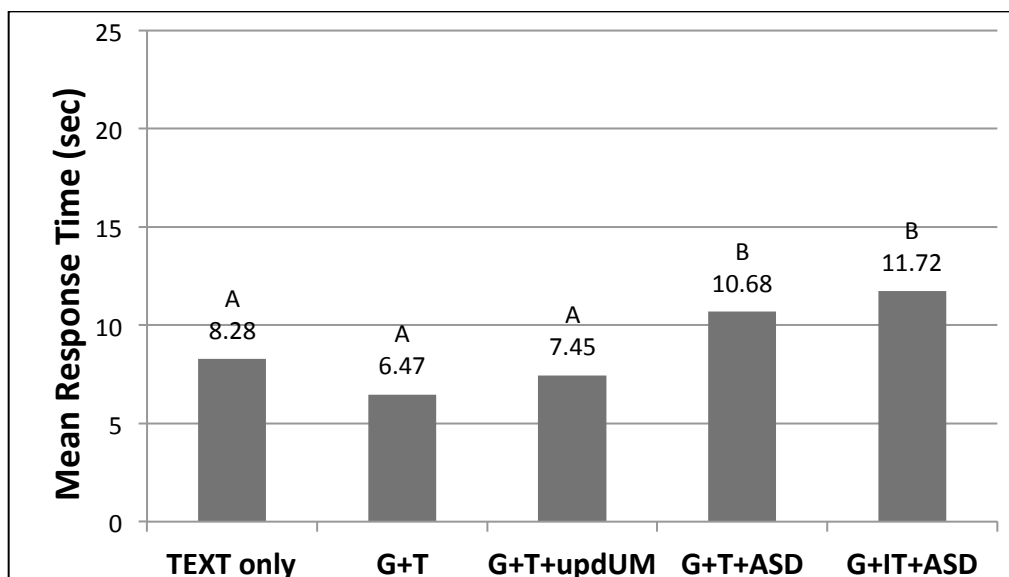


Figure 24. Two Element MRT for the FORMAT by RESPONSE Interaction.

As indicated by the asterisks in Figure 24, two FORMATS result in differences with respect to MRT to correctly accept or correctly reject a clearance. Formats with an ASD resulted in longer response times to accept a clearance. For the remaining formats time to correctly accept or reject were not significantly different, however, the trend was for longer response times to accept a clearance.

For the main effect of FORMAT illustrated in Figure 25, conditions with an ASD showed higher response times. There was no difference in MRT for TEXT and G+T or G+T+updUM with two elements.

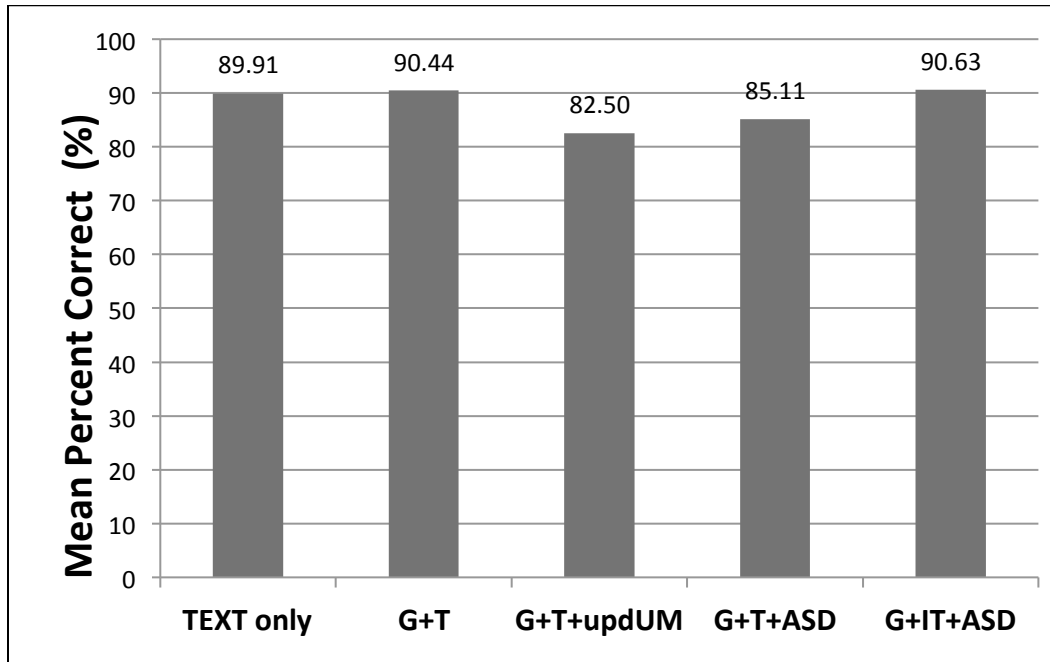
The main effect of RESPONSE shows that correctly accepting a clearance ( $X = 9.82$  sec) takes longer than correctly rejecting a clearance ( $X = 8.02$  sec).



**Figure 25. Two Element MRT as a Function of FORMAT.**

#### **3.1.14.2. Mean Percent Correct Two Element**

The two main effects RESPONSE ( $p = 0.0317$ ) and FORMAT ( $p = 0.0286$ ) were significant. The two-way interaction was not significant. Figure 26 illustrates the mean percent correct for each format. Because of the conservative nature of the Tukey-Kramer post-hoc test, it showed no statistically significant differences for paired comparisons. Based on the ANOVA we can state that the G+T+updUM condition is statistically different than the highest mean percent correct which was found for G+IT+ASD.



**Figure 26. Two Element MPC as a Function of FORMAT.**

For the main effect of RESPONSE, pilots responded with higher accuracy when correctly rejecting ( $X=90.06\%$ ) versus correctly accepting a clearance ( $X=85.38$ ).

### 3.1.15. Three Element Clearances

Table 6 lists the five three element clearances evaluated and the formats tested.

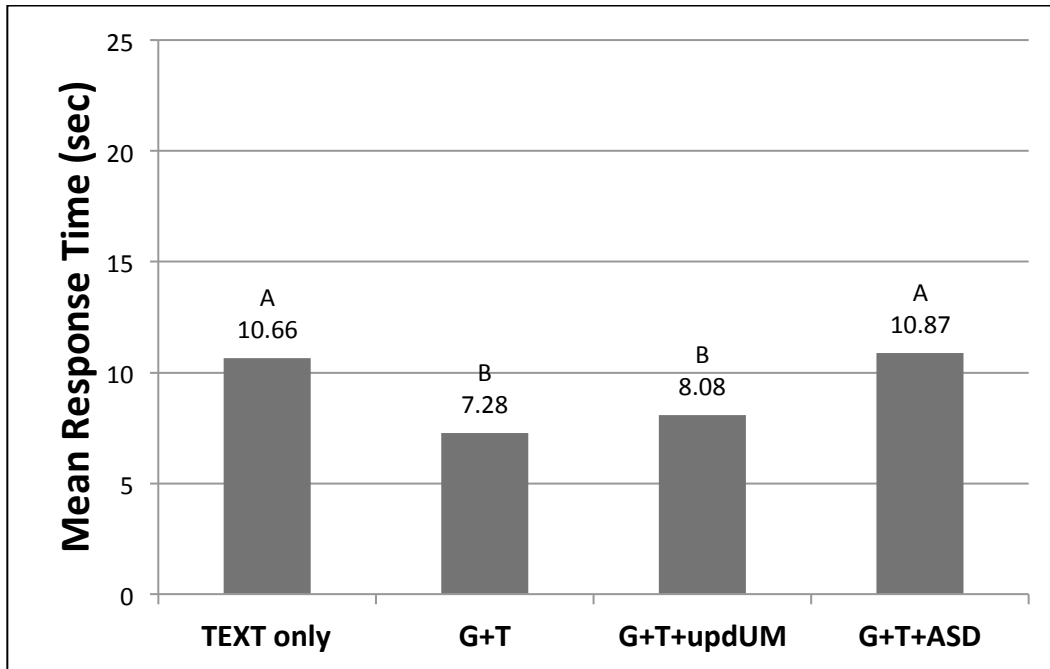
**Table 6 Three Element Clearances and Format Tested**

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
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	*	*	*	*

### 3.1.15.1. Mean Response Time Three Element

The ANOVA for response time indicated that both main effects RESPONSE ( $p = \leq 0.0001$ ) and FORMAT ( $p = 0.0004$ ) resulted in significant differences. The interaction of FORMAT\*RESPONSE was not statistically significant.

Figure 27 illustrates the main effect of FORMAT. There is a significant difference between TEXT and the two G+T conditions. When ASD is added to G+T, response time increases. This is most likely due to the need to view two separate displays.

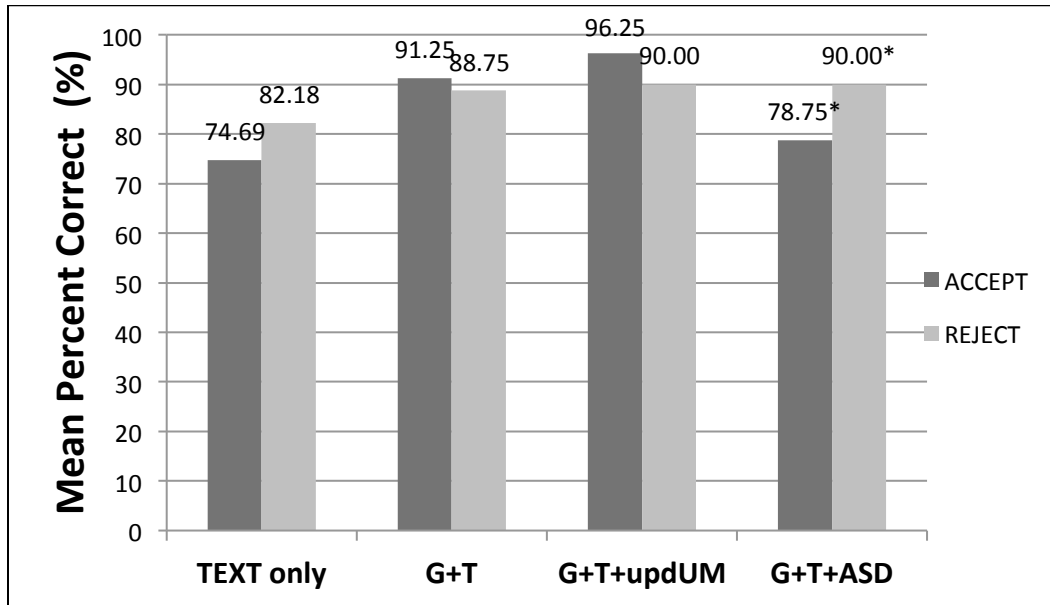


**Figure 27. Three Element MRT as a Function of FORMAT.**

For the main effect of RESPONSE pilots correctly rejected ( $x = 8.14$ ) clearances significantly faster than correctly accepting ( $x = 10.31$ ) them.

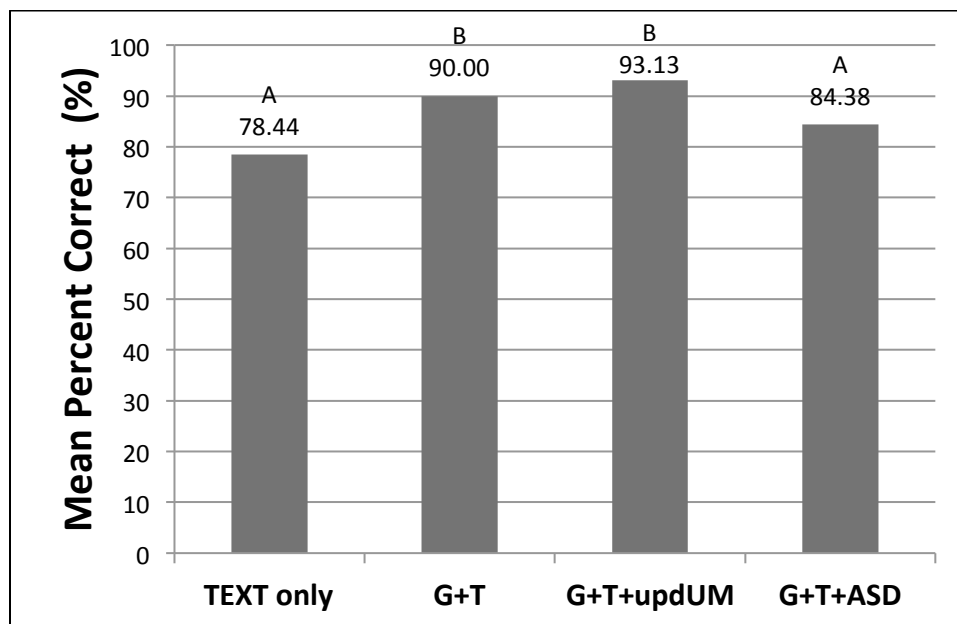
### 3.1.15.2. Mean Percent Correct Three Element

The ANOVA for mean percent correct indicated that the main effect of FORMAT ( $p = 0.0027$ ) and the interaction FORMAT\*RESPONSE ( $p = 0.0499$ ) were statistically significant. Figure 28 illustrates the interaction. There is a significant difference between correctly accepting or correctly rejecting a clearance for G+T+ASD only. All other formats resulted in no significant differences between accept and reject.



**Figure 28. Three Element MPC for the FORMAT by RESPONSE Interaction.**

The main effect of FORMAT is illustrated in Figure 29. There is a significant difference between TEXT and the two G+T formats (without ASD). When adding ASD to G+T, percent correct declines. Text results in significantly lower percent correct than Graphics + Text conditions.



**Figure 29. Three Element MPC as a Function of FORMAT.**

### 3.1.16. Four Element Clearances

Table 7 lists the 4 four element clearances evaluated and the formats tested.

**Table 7. Four Element Clearances and Formats Tested**

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
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	*	*	*		*

#### 3.1.16.1. Mean Response Time Four Element

The main effects of RESPONSE ( $p \leq .0001$ ) and FORMAT ( $p = .0024$ ) were statistically significant as was the interaction ( $p \leq .0001$ ). Figure 30 illustrates the significant interaction. There were statistically significant differences in MRT for correctly accepting versus correctly rejecting clearances for all graphic formats, with higher MRT when correctly accepting clearances. However, the largest differences were found for graphic conditions that included the ASD. There was no difference in MRT for type of response for TEXT.

The main effect of FORMAT is illustrated in Figure 31. G+T+updUM was significantly different from TEXT and G+T+ASD. The condition with integrated graphics did not result in higher MRT even though ASD was included, indicating that the integration of text may have supported performance. It should be noted that there is no significant difference between G+T and G+T+updUM, and also no significant difference between G+T and TEXT. This slight difference between G+T and G+T+updUM is most likely due to reduction in variance associated with using more subjects in the condition of G+T+updUM (20 pilots) compared to G+T (8 pilots).

The main effect of RESPONSE is similar to all previous findings. Correctly accepting a clearance takes longer ( $X=12.56$ ) than rejecting ( $X=9.87$ ) a clearance. This has to be evaluated with respect to the interaction. With TEXT there was no difference.

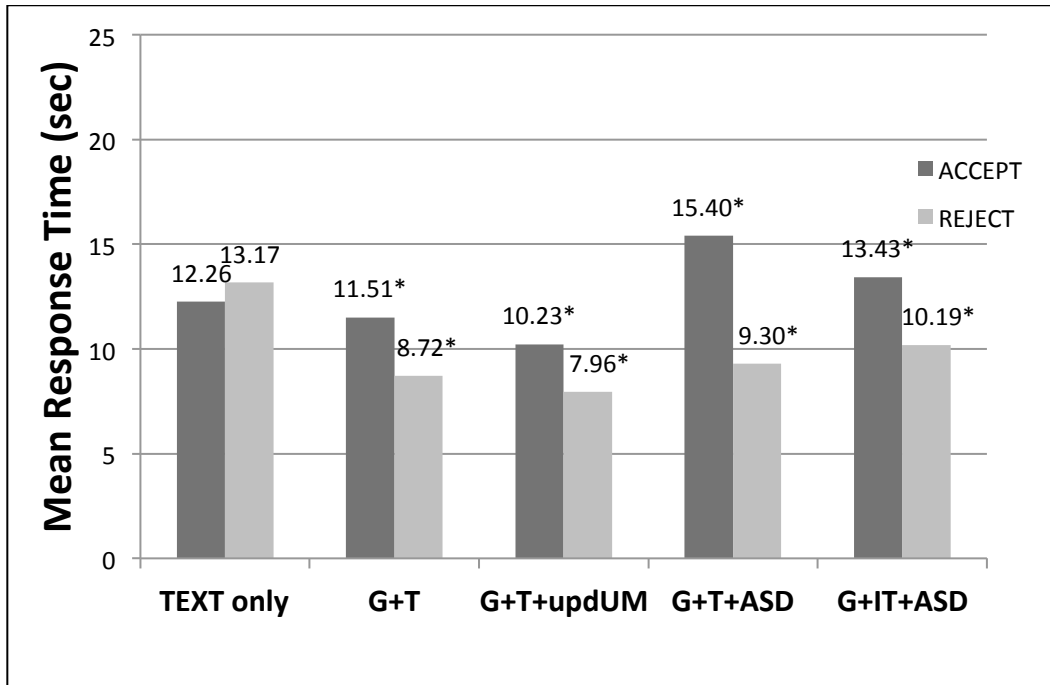


Figure 30. Four Element MRT for the FORMAT by RESPONSE Interaction.

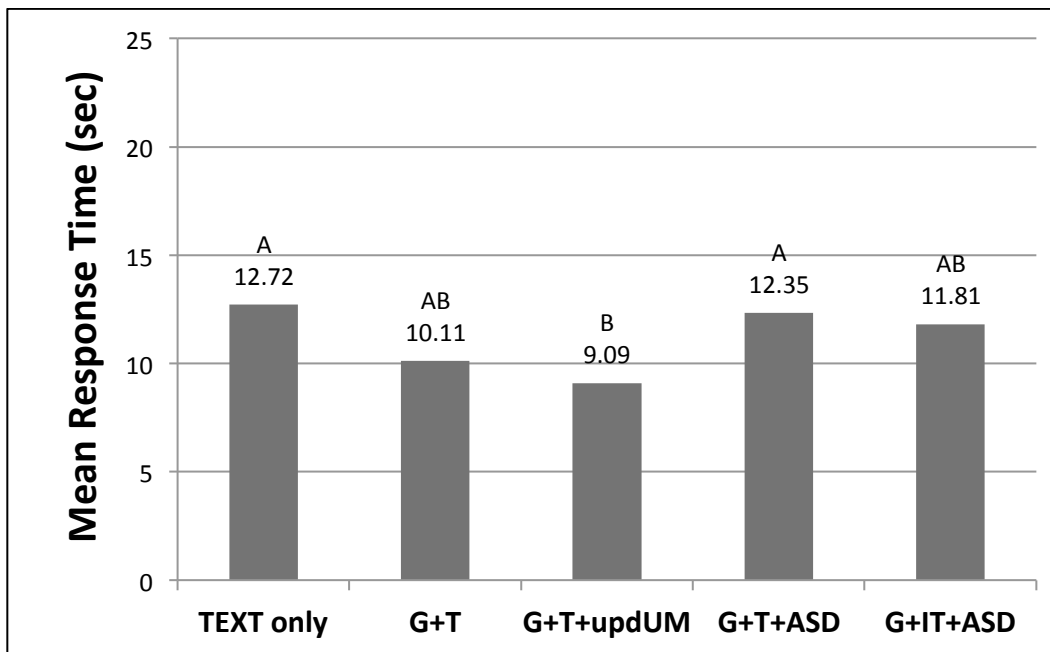


Figure 31. Four Element MRT as a Function of FORMAT.



### 3.1.16.2. Mean Percent Correct Four Element

The ANOVA results indicated a significant main effect of RESPONSE ( $p \leq .0001$ ). The main effect of RESPONSE indicated that pilots correctly rejected clearances at a higher percentage ( $X = 93\%$ ) than correctly accepting them ( $X = 70.52\%$ ). The main effect for FORMAT was nearly significant at  $p = 0.0509$ . This is only 0.01 greater than 0.05. The trend is illustrated in Figure 32 for the reader to determine the significance. The interaction was not significant.

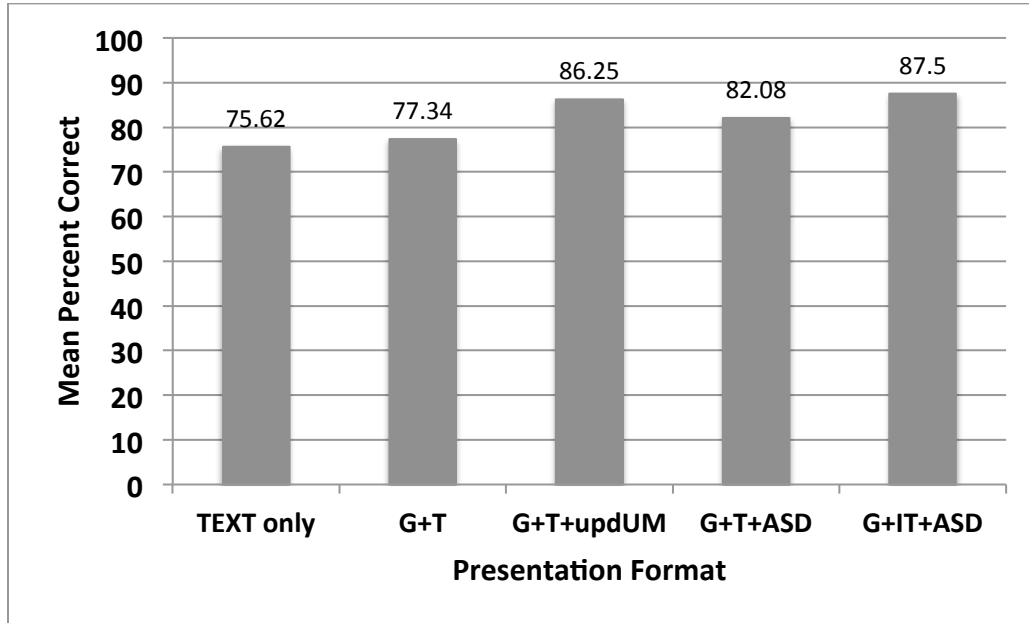


Figure 32. Four Element MPC as a Function of FORMAT.

### 3.1.17. Five Element Clearances

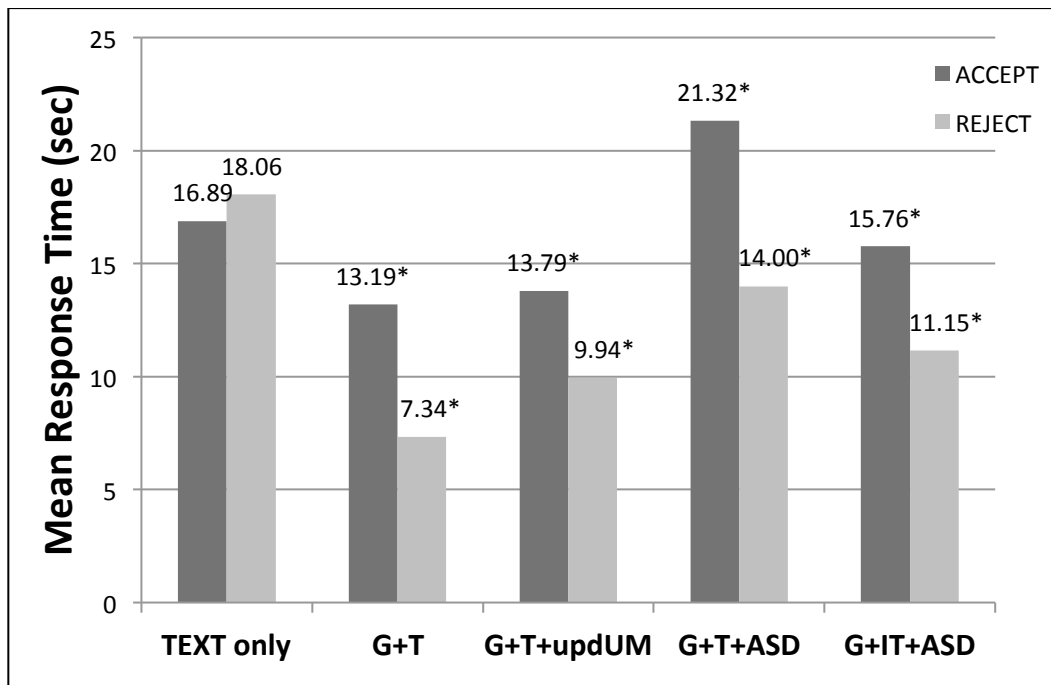
Table 8 lists the five element clearances evaluated and the formats tested. Only three UMs were evaluated..

Table 8. Five Element Clearances and Formats Tested.

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] 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	*	*	*	*	*

### 3.1.17.1. Mean Response Time Five Element

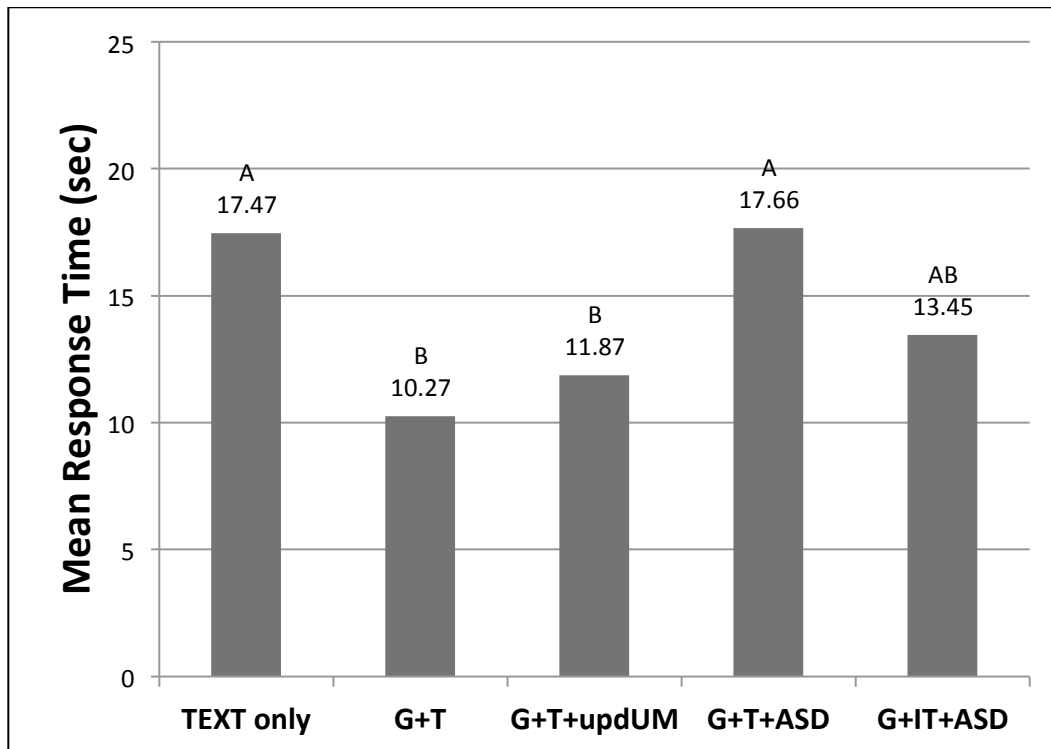
The ANOVA for MRT resulted in significant main effects (RESPONSE,  $p \leq .0001$ ; FORMAT,  $p \leq .0001$ ) and a significant interaction ( $p = 0.0005$ ). Figure 33 illustrates the interaction. Under graphic formats, MRT is always slower when pilots correctly accepted versus correctly rejected a clearance. However, the magnitude of this difference varies from seven seconds under the condition of G+T+ASD to a low of 3.85 seconds for G+T+updUM. There is no difference in MRT for correctly accepting versus correctly rejecting a clearance for TEXT. Mean response times for text are higher than for G+T and G+updUM conditions.



**Figure 33. Five Element MRT for the FORMAT by RESPONSE Interaction.**

The main effect of FORMAT is illustrated in Figure 34. G+T and G+T+updUM and G+IT+ASD are not significantly different from one another. Although adding ASD decreases MRT under the G+T+ASD condition, it appears that integrating text with the graphics provided a benefit that overrides the decrement of adding an ASD. Overall, TEXT resulted in the poorest performance along with G+T+ASD.

The main effect of RESPONSE was similar to all other results discussed. Correctly accepting (X = 16.19) a clearance takes longer than rejecting a clearance (X = 12.10).



**Figure 34. Five Element MRT as a Function of FORMAT.**

### **3.1.17.2. Mean Percent Correct Five Element**

The ANOVA results indicated that the main effect RESPONSE ( $p \leq .0001$ ) and FORMAT ( $p = .0022$ ) were statistically significant as well as the interaction ( $p = .0064$ ). Figure 35 illustrates the interaction. Mean Percent Correct was significantly higher when rejecting a clearance than accepting a clearance except under the condition of G+IT+ASD in which there was no difference. The magnitude of the differences ranged from 31.67% for TEXT to 11.25% for G+T+ASD.

The main effect of FORMAT is illustrated in Figure 36 and must be considered in light of the interaction. The two conditions resulting in the highest percent correct were G+T+updUM and G+IT+ASD. Again this signifies that integrated text may support performance. The two conditions were not significantly different from one another and G+T+updUM was not statistically different from any other format.

The main effect of RESPONSE was similar to all previous results where mean percent correct is higher when correctly rejecting a clearance ( $X = 93.08$ ) compared to correctly accepting a clearance ( $X = 79.08$ ).

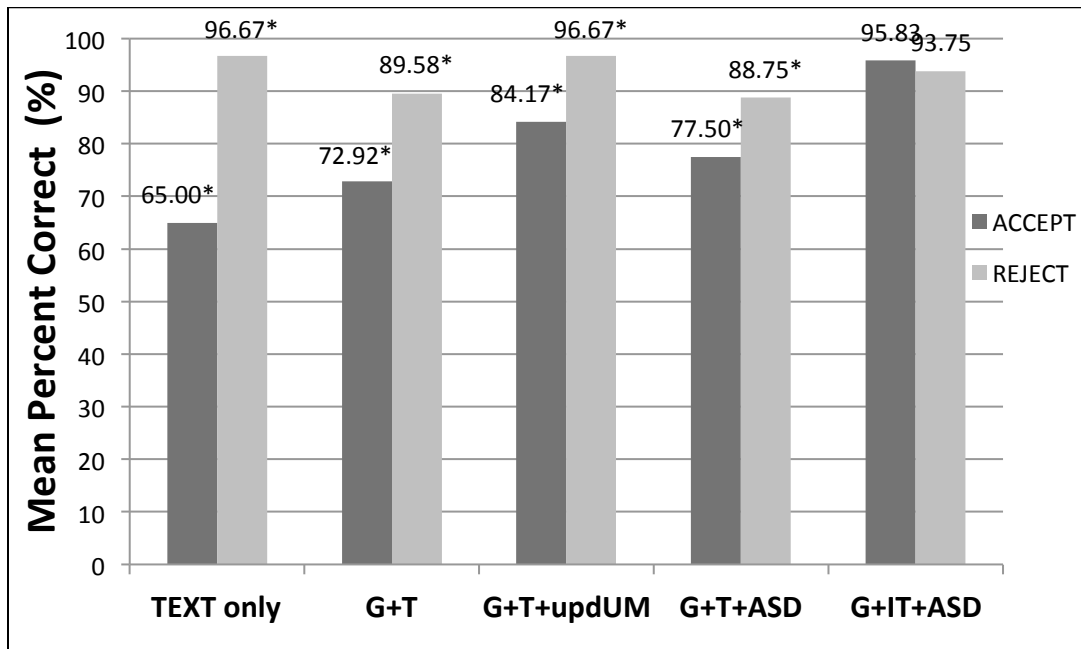


Figure 35. Five Element MPC for the FORMAT by RESPONSE Interaction.

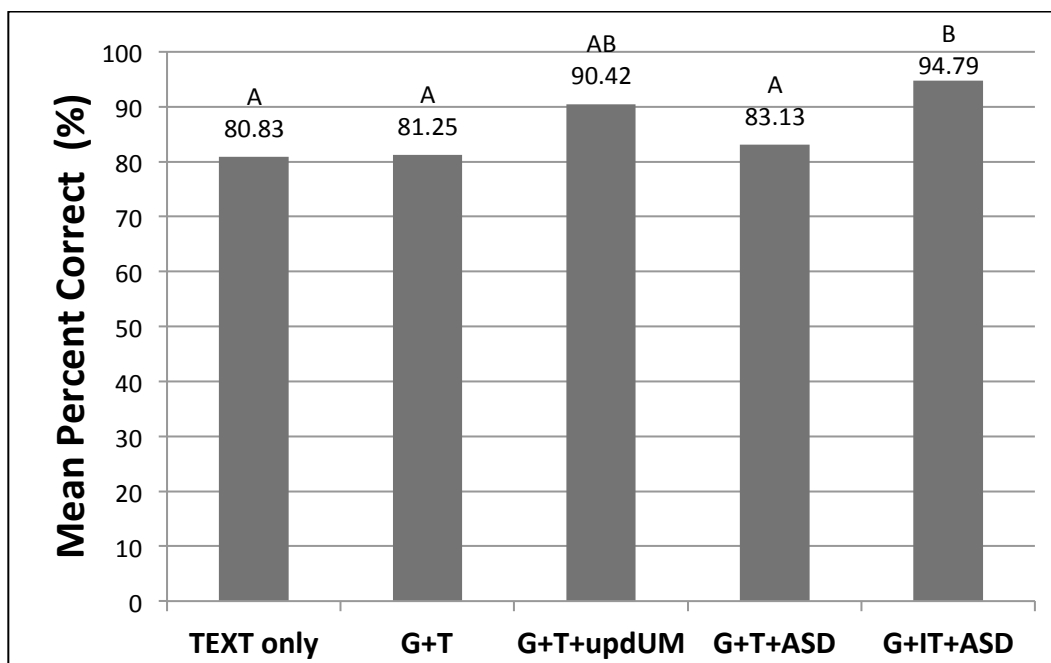


Figure 36. Five Element MPC as a Function of FORMAT.

### 3.1.18. Six Element Clearances

Table 9 lists the two six element clearances tested across and the formats tested.

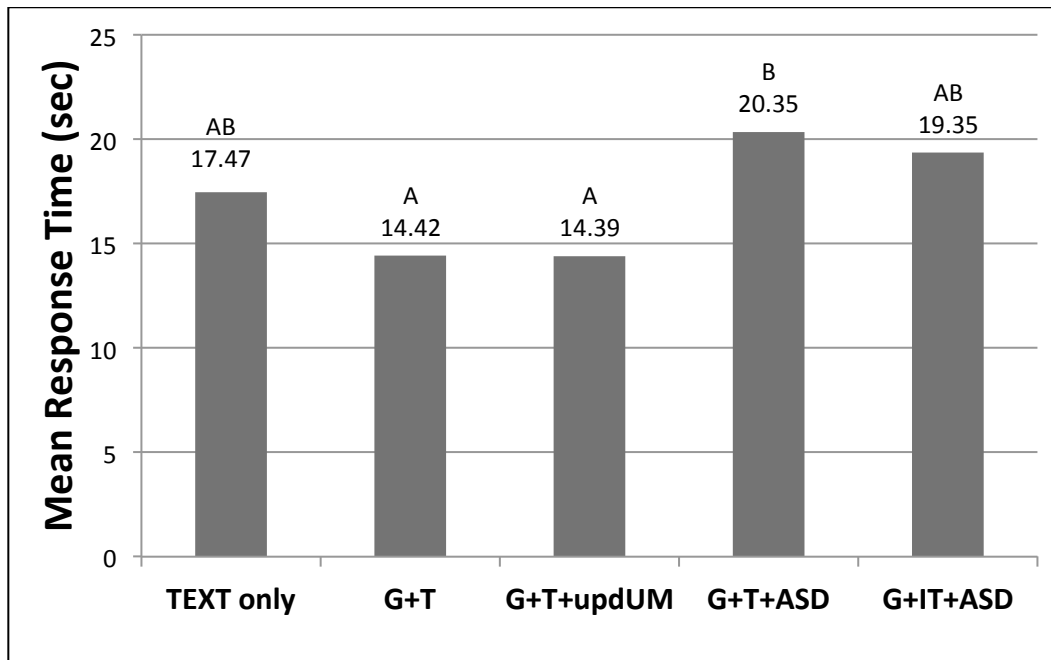
**Table 9. Six Element Clearances and Formats Tested.**

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 [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	*	*	*	*	*

#### 3.1.18.1. Mean Response Time Six Element

The ANOVA for MRT indicated that both main effects, RESPONSE ( $p = 0.0062$ ) and FORMAT ( $p = 0.0007$ ) were statistically significant. There was no significant interaction. Figure 37 illustrates the main effect of FORMAT. G+T+ASD resulted in the longest response times and was not significantly different from TEXT or G+IT+ASD. MRT was similar between G+T and G+T+updUM had the fastest response times but they were not significantly different from TEXT. It is important to note that as the number of elements in a clearance increased there were less data and therefore more variability. However, the trends hold across number of elements under the G+T and G+T+updUM conditions.

The main effect of RESPONSE was significant with MRT higher when correctly accepting a clearance ( $X = 18.59$ ) versus correctly rejecting a clearance ( $X = 15.81$ ).



**Figure 37. Six Element MRT as a Function of FORMAT.**

### 3.1.18.2. Mean Percent Correct Six Element

The ANOVA for mean percent correct 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 accepting them ( $x = 75.63\%$ ).

### 3.1.19. Nine Element Clearances

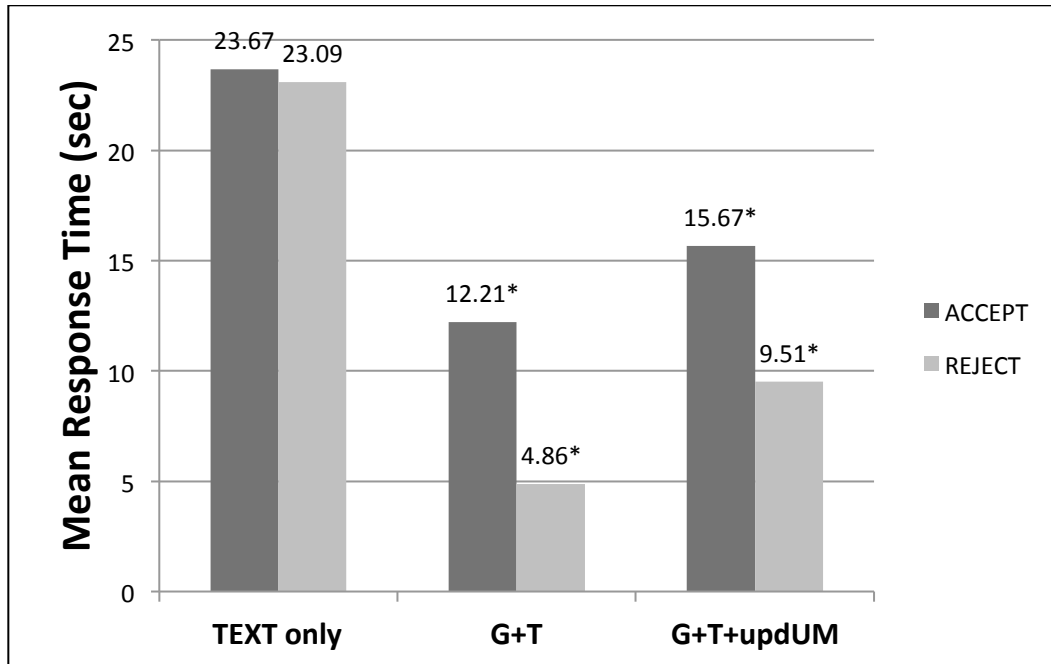
Table 10 lists the nine element clearance evaluated and the formats tested.

**Table 10. Nine Element Clearances and Formats Tested.**

Clearance		FORMAT		
		Number of subjects tested		
SC-214 UM Text	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	*	*	*

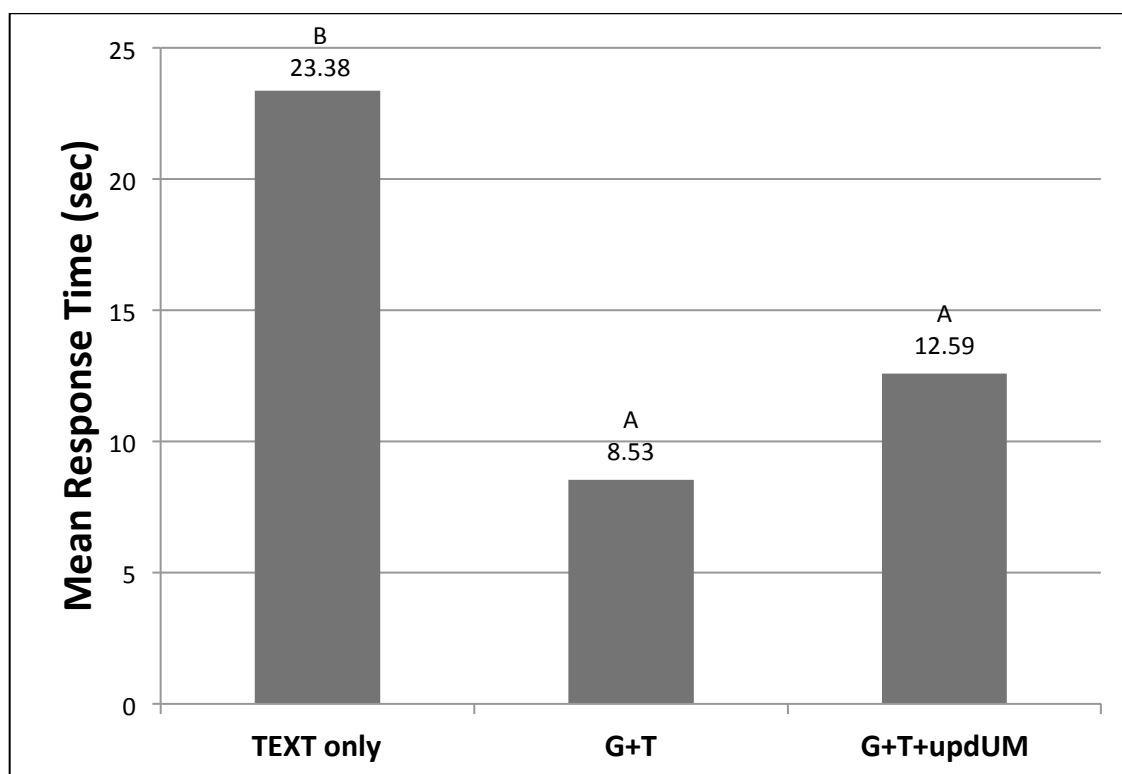
### 3.1.19.1. Mean Response Time Nine Element

The ANOVA indicated that both main effects, RESPONSE ( $p = <.0001$ ) and FORMAT ( $p = <.0001$ ), and the interaction FORMAT\*RESPONSE ( $p = 0.0474$ ) were statistically significant. Figure 38 illustrates the interaction. Under the two graphic conditions, MRT was significantly higher when pilots correctly accepted a clearance compared to correctly rejecting a clearance. The magnitude is greater for G+T. For TEXT there is no difference and MRT is almost double overall.



**Figure 38. Nine Element MRT for the FORMAT by RESPONSE Interaction.**

The main effect of FORMAT is illustrated in Figure 38. For the nine element clearance there is a significant difference in MRT for TEXT compared to both G+T conditions which are not significantly different. The greatest difference is 14.85 seconds.



**Figure 39. Nine Element MRT as a Function of FORMAT.**

The main effect of RESPONSE showed that MRT was slower when pilots correctly accepted a clearance ( $X = 17.18$ ) compared to rejecting a clearance ( $X = 12.48$ ).

### **3.1.19.2. Mean Percent Correct Nine Element**

The ANOVA for mean percent correct indicated a significant main effect of RESPONSE. There were no other significant effects. The mean percent correct when correctly rejecting a clearance ( $X = 94.17\%$ ) is significantly higher than correctly accepting a clearance ( $x = 45.83\%$ ). This is a difference of 48.34%. These data indicated that the pilots did not accept reroutes that were correct because they did not feel comfortable with the information.

### **3.1.20. General Summary of MRT Results**

Table 11 summarizes the results of MRT by number of elements. An X in the table indicates a significant result was found. The asterisk under each format represents significant simple-effects when there was a significant interaction.



**Table 11. Summary Table of Mean Response Time Statistical Effects.**

Number of Elements	Significant Main Effect of FORMAT	Significant Main Effect of RESPONSE	Significant Interaction FORMAT x RESPONSE	Significant Differences within the Interaction. Simple-Effects F-test by FORMAT.				
				TEXT	G+T	G+T+updUM	G+T+ASD	G+IT+ASD
1	X	X	X			*	*	Not Tested
2	X	X	X				*	*
3	X	X						Not Tested
4	X	X	X		*	*	*	*
5	X	X	X					
6	X	X						
9	X	X	X		*	*	Not Tested	Not Tested
* denotes that for the FORMAT condition there was a significant difference in RESPONSE. In all cases MRT for a correct accept was slower than a correct reject.								

### 3.1.21. General Summary Table of MPC Statistical Effects

Table 12 summarizes the results of MPC for each number of elements. An X in the table indicates a significant result was found. The asterisk under each format represents significant simple-effects when there was a significant interaction.

### 3.1.22. Pilot Comments

During testing pilot verbal comments were recorded. Listed below is 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 needed to rejoin they needed a specific point for the rejoin. Pilots indicated that when REJOIN is paired with “BEFORE PASSING”, a range of possibilities exist for the pilot. The pilot could rejoin at his/her discretion. Pilots recommended that instead of using “BEFORE PASSING” use “REJOIN by (POSITION)” or “REJOIN ABEAM (POSITION)” to limit the pilot’s options and reduced ambiguity and confusion with “REJOIN” UMs.

**Table 12. Summary of Mean Percent Correct Statistical Results by Element.**

Number of Elements	Significant Main Effect of FORMAT	Significant Main Effect of RESPONSE	Significant Interaction FORMAT x RESPONSE	Significant Differences within the Interaction. Simple-Effects F-test by FORMAT.				
				TEXT	G+T	G+T+u pdUM	G+T+ASD	G+IT+ASD
1								Not Tested
2	X	X						
3	X		X				*	Not Tested
4		X						
5	X	X	X	*	*	*	*	
6		X						
9		X					Not Tested	Not Tested
* denotes that for the FORMAT condition there was a significant difference in RESPONSE. In all cases MPC for a Correct Accept was lower than a correct reject.								

- 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 served 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 indicated 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 rerouting clearance message such as “Proceed Direct to” or “Rejoin Route at”.
- When pilots were asked about the use of graphics within the 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 more quickly compared to text alone. 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 3 pilots thought it was helpful. The statistical results showed it slowed response time.

### 3.2. Discussion

In this section, each individual hypothesis is discussed with respect to the results.

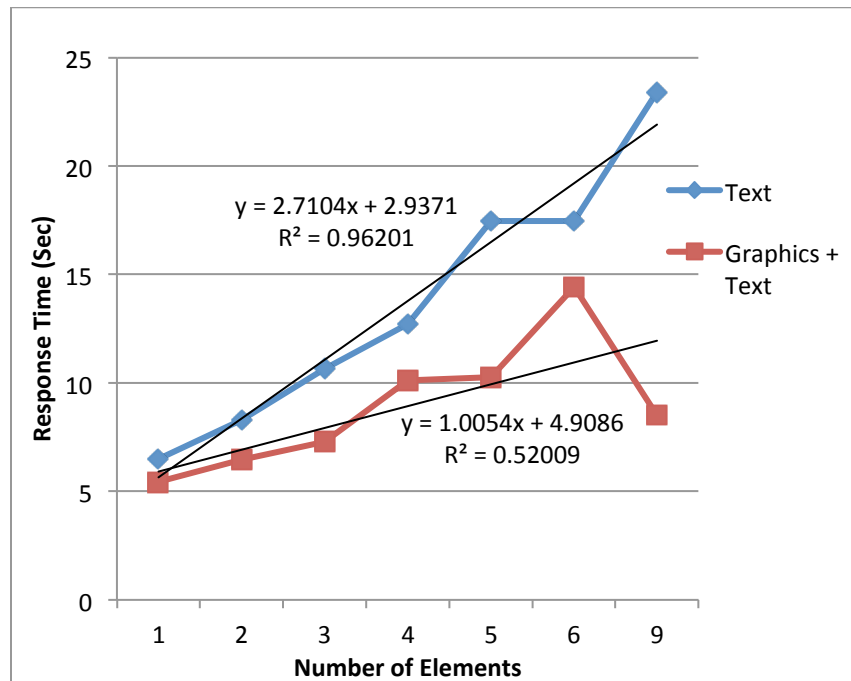
#### 3.2.1. Hypothesis 1: There is no difference in mean response time to interpret a clearance between TEXT and Graphics +Text Conditions

The exploratory experiment was designed to evaluate performance differences between text and graphic conditions by comparing the baseline TEXT condition to the G+T condition. As previously stated, G+T and G+T+updUM were expected to be similar because the updates were just corrections to the UM and not the graphic format. Table 13 summarizes the MRT data across the number of elements in a clearance. Differences are indicated by letters across rows. If the letters are different in the row, there was a significant difference. Grey boxes show where differences are located. To support the reader the MRT in seconds is also included in the Table. There is only one difference between G+T and G+T+updUM; under the one element clearance. The difference is only 2.8 seconds. Therefore we conclude that these two conditions are similar with respect to response time.

Figure 40 illustrates the trend of increased response time as the number of elements increase for both TEXT and G+T. The increase in MRT for TEXT, that is the slope, is much greater as the number of elements increase compared to that of G+T.

**Table 13. Mean Response Time Across Number of Elements.**

Number of Elements	TEXT	G+T	G+T+updUM	Notes
1	AB (6.48)	B (5.44)	A (8.24)	G+T+updUM > G+T by 2.8 sec
2	A (8.28)	A (6.47)	A (7.45)	
3	A (10.66)	B (7.28)	B (8.08)	
4	A (12.72)	AB (10.11)	B (9.09)	
5	A (17.47)	B (10.27)	B (11.87)	
6	A (17.47)	A (14.42)	A (14.39)	
9	A (23.38)	B (8.53)	B (12.59)	



**Figure 40. MRT for TEXT and G+T FORMATS as a Function of Number of Elements.**

The decrease of MRT for the nine element clearance is most likely due to the fact that pilots tended to reject these clearances more than accept them. (Correct rejections were 94.17% while correct accepts were 45.83%). As the results indicated, correctly rejecting a clearance was faster than correctly accepting a clearance.

The results indicate that a hybrid of graphics and text is not needed for one and two element clearances. However, for three elements and above graphics and text improved MRT. Therefore the null hypothesis is rejected. Graphics did improve MRT for interpreting DataComm clearances. One recommendation specified in Volume I stated that although one and two element clearances did not show a difference in this study, all clearances should include graphics in order to avoid pilot confusion due to inconsistent use of graphics. Pilots may wonder why graphics are not used in every circumstance.

### **3.2.2. Hypothesis 2. There is no significant different in mean response time among the four graphic presentation formats.**

The results indicated that there are some differences among the graphic formats evaluated. Specifically when the ASD was added underneath the ND to provide altitude clearance information MRT increased. Pilots commented that they did not think it was necessary. Altitude was available on the ND. Table 14 summarizes the MRT for the main effect of FORMAT. Because the interaction between FORMAT and RESPONSE (correct accept vs. correct reject) was ordinal, it is feasible to discuss the main effects. An ordinal interaction means that the direction of the interacting variable is always the same. Regardless of FORMAT, correctly accepting a clearance always took longer than correctly rejecting a clearance.

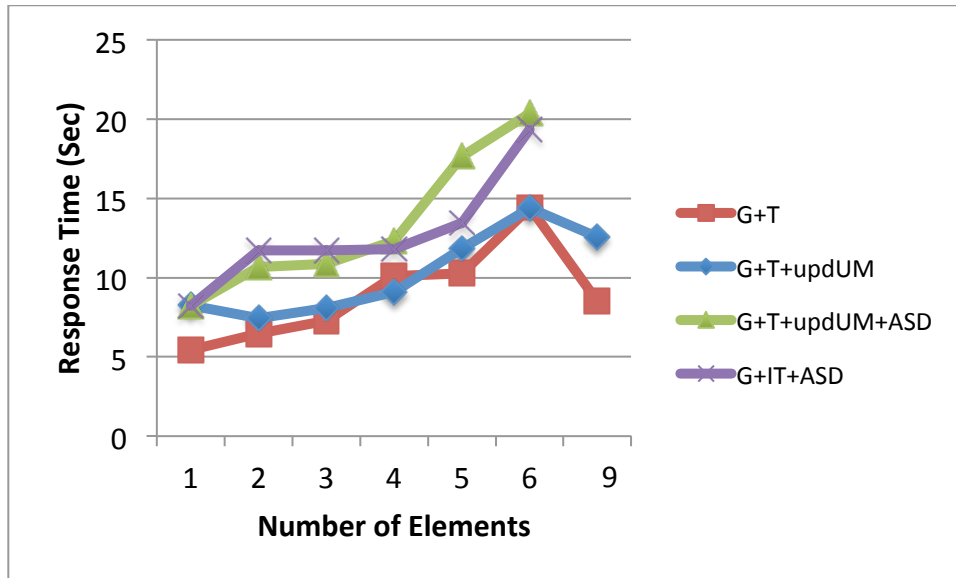
The shaded gray area in Table 14 indicated conditions where G+T+ASD significantly increased MRT. What is interesting to note is that when text was integrated into the graphic and an ASD was included (G+IT+ASD), MRT performance was at times similar to G+T conditions (no ASD). Specifically when there were four, five or six elements, there was no difference between this condition and G+T and G+T+updUM conditions. It appears that integrating text into the graphic rather than text to the side may improve performance. It seemed to offset the poor performance when using the ASD. This condition was not tested with many clearances and number of subjects was small. Therefore, additional studies must be conducted to determine the benefits of integrated text.

**Table 14. Mean Response Time for Graphic Formats By Number of Elements.**

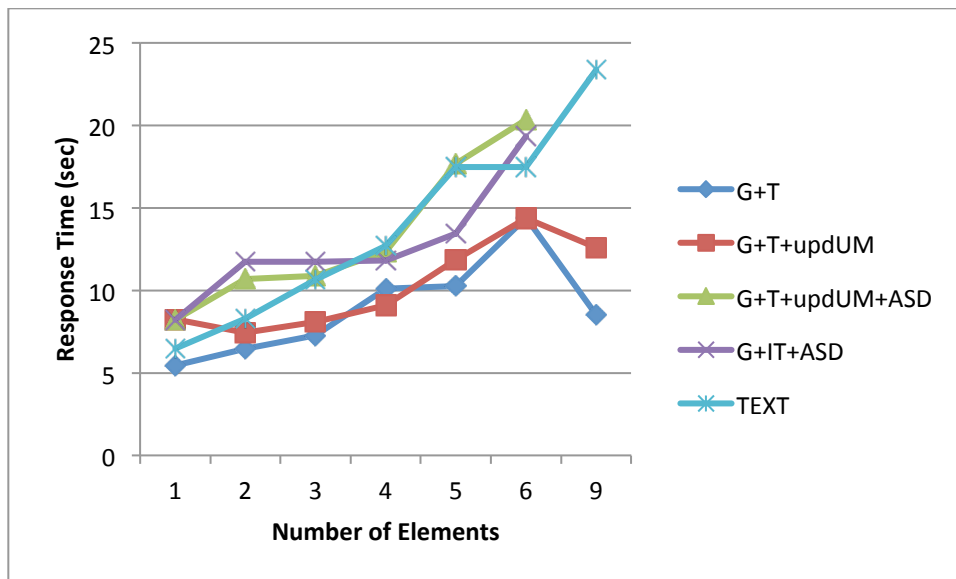
Number of Elements	G+T	G+T+updUM	G+T+ASD	G+IT+ASD
1	A (5.44)	B (8.24)	B (8.22)	Not tested
2	A (6.47)	A (7.45)	B (10.68)	B (11.72)
3	A (7.28)	A (8.08)	B (10.87)	Not tested
4	AB (10.11)	B (9.09)	A (12.37)	AB (11.81)
5	A (10.27)	A (11.87)	B (17.66)	AB (13.45)
6	A (14.42)	A (14.39)	B (20.35)	AB (19.35)
9	A (8.53)	A (12.59)	Not tested	Not tested

Figure 41 illustrates the same data comparing each format across number of elements. The graph illustrates that the two conditions with ASD are grouped together across number of elements, while the G+T hybrid conditions (G+T+ updUM) are grouped with lower MRTs. Figure 42 adds TEXT to the same graph for comparison. TEXT and G+T+ASD results are very similar.

Based on the results, the null hypothesis stating that there is no difference among graphic formats is rejected. Adding the ASD decreases MRT performance. G+T resulted in fastest response times as number of elements increased.



**Figure 41. MRT for Graphic FORMATS as a Function of Number of Elements.**

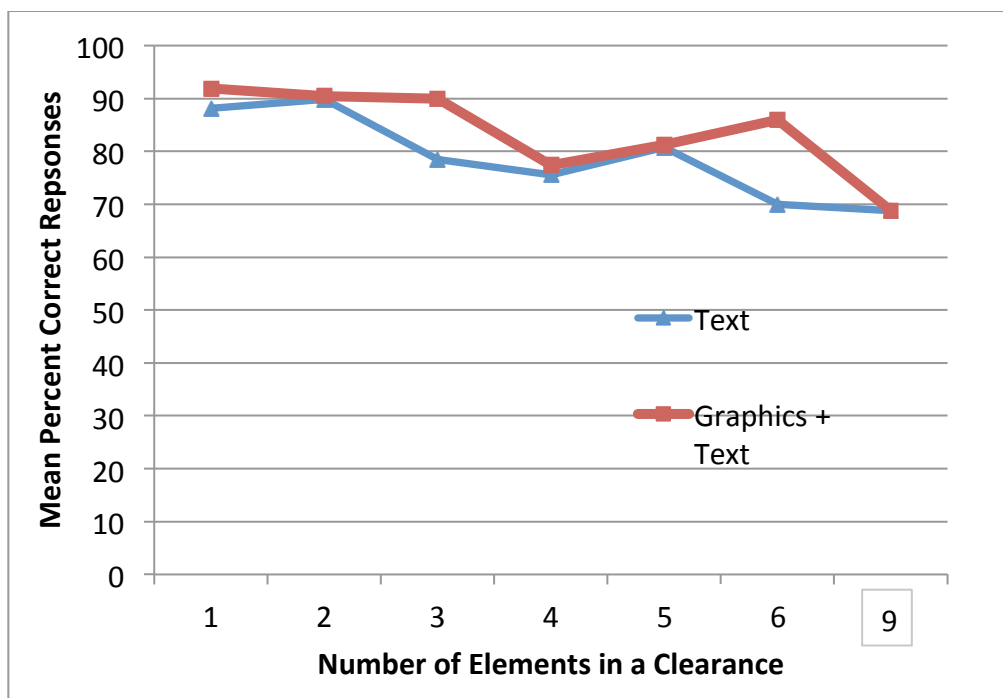


**Figure 42. MRT for each FORMAT as a Function of Number of Elements.**

### 3.2.3. Hypothesis 3. There is no significant difference in percent correct interpretation between TEXT and Graphics + TEXT.

As previously indicated, the test of hypothesis 3 is based on the data from Text and G+T.

Figure 43 illustrates the effect of Text versus G +T as a function of number of elements for mean percent correct. There is a significant difference in mean percent correct only at three and six elements, where graphics resulted in fewer errors. There were only 10 pilots for this comparison. There were no significant differences across the other number of elements, but performance for graphics was as good as text in these cases. Based on these data only, the null hypothesis is rejected. We would expect a significant difference across 3, 4, 5, 6 and 9 elements. However, the trend indicates that a larger subject pool would reduce the variance.



**Figure 43. Mean Percent Correct as a Function of Format for Text and Graphic Hybrid Conditions.**

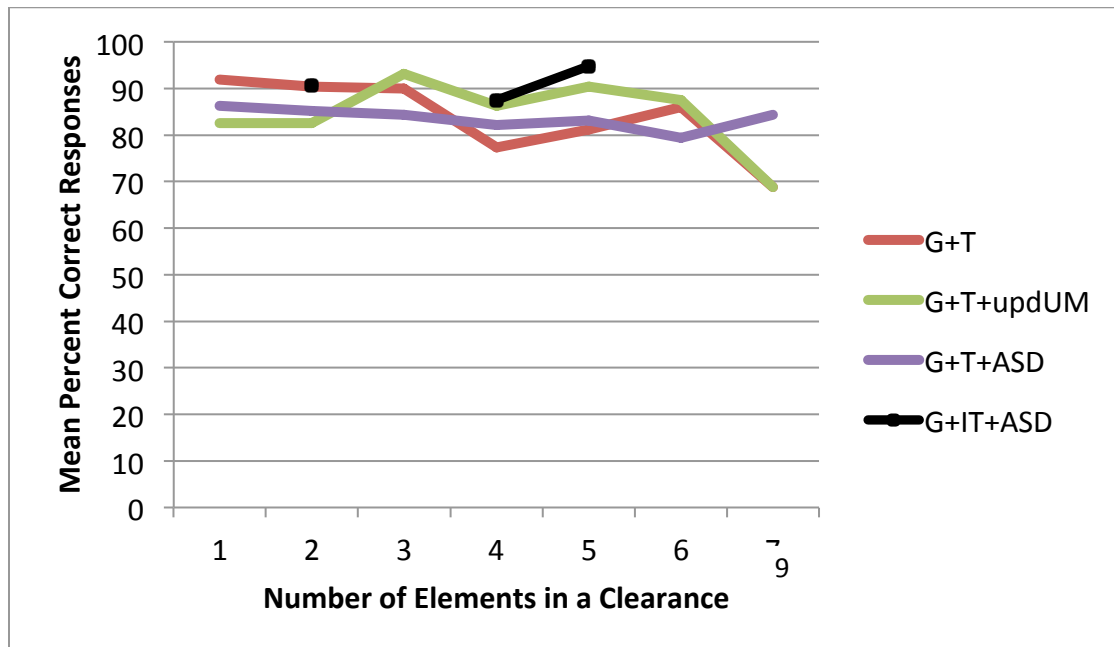
**Table 15. Mean Percent Correct as a Function of Text and Graphic Hybrid Conditions.**

<b>Number of Elements</b>	<b>TEXT</b>	<b>G+T</b>	<b>G+T+updUM</b>	<b>G+T+ ASD</b>	<b>G+IT+ASD</b>	<b>Notes</b>
1	A 88.18	A 91.96	A 82.5	A 86.25	Not collected	
2	AB 89.91	A 90.44	B 82.50	AB 85.11	Not collected	G+T+updUM had > # of subjects than G+T
3	A 78.4	B 90.00	B 93.13	A 84.35	Not Collected	
4	A 76.52	A 77.34	A 82.08	A 86.25	A 94.79	P = .0509. Trend is text greater error
5	A 80.83	A 81.25	AB 90.42	A 83.12	B 94.79	
6	B 70	A 85.93	A 87.50	A 79.35	A 84.37	
9	A 72.5	A 68.75	A 68.75	Not Collected	Not Collected	Pilots reject most of the time.

#### **3.2.4. Hypothesis 4. There is no significant difference in mean percent correct interpretation among the four graphic presentation formats.**

Table 15 above provides the mean percent correct across the graphic conditions. Figure 44 illustrates the data graphically. There was one significant difference between G+T and G+T+udpUM for two element clearances. However, this difference may be related to the number of subjects. Twenty-four pilots used G+T+udpUM whereas only 10 pilots participated in G+T. Although the four element condition showed no significant differences, the p value was only .01 below the 0.05 criterion. In this case the trend is for G+IT+ASD to be significantly different than G+T. The five element clearance also showed significant difference for G+IT+ASD compared to G+T and G+T+ASD. For six element and nine element clearances there was no difference across graphic formats. Based on these findings the hypothesis was rejected. There is a need for additional research to ensure the difference in mean percent correct across graphic formats. There is a strong trend suggesting the need for additional research related integrating text onto the ND rather than separating text (G+IT+ASD) while eliminating the ASD.





**Figure 44. Mean Percent Correct Accept as a Function of Number of Elements and Graphic Format.**

### 3.3. Summary Discussion for Experiment I

Experiment I results indicated that overall as the number of elements in a clearance increased the time required to interpret the clearance increased and errors increased. Hybrid conditions with graphics + text improved performance when there were 3 or more elements in a clearance. Graphics provided an opportunity for pilots to compare their mental model of their current and future aircraft positions to the graphic. Text alone required pilots to mentally project their current and future condition on to the ND.

More importantly the overall objective of this study, to support creation of human factors recommendations, was successfully completed. The recommendations are presented in Volume I. The technique for rapid prototyping of graphic formats using a simple tool for pilot interpretation (DC-MAT) was also successful.

## **4. Method Experiment II. Evaluation of DMs Using Text for Creating Downlink Messages with and without graphic display of DMs**

### **4.1. Experimental Design**

This exploratory study presented a format that utilized text for creating DMs during a HITL experiment using a non-moving base flight simulation. In addition to the text, a graphic was provided that illustrated the DM on the ND next to the original flight path. This exploratory study was used to obtain response times and errors with respect to clearance presentation and DM creation. The primary objective was to obtain feedback that could be used to create human factors recommendations. No independent variables were manipulated, thus there are no hypotheses.

The human performance dependent variables collected included:

- 1) Time to correctly accept clearance (WILCO).
- 2) Time to correctly reject a clearance (Unable)
- 3) Time to create a DM (after it was rejected)

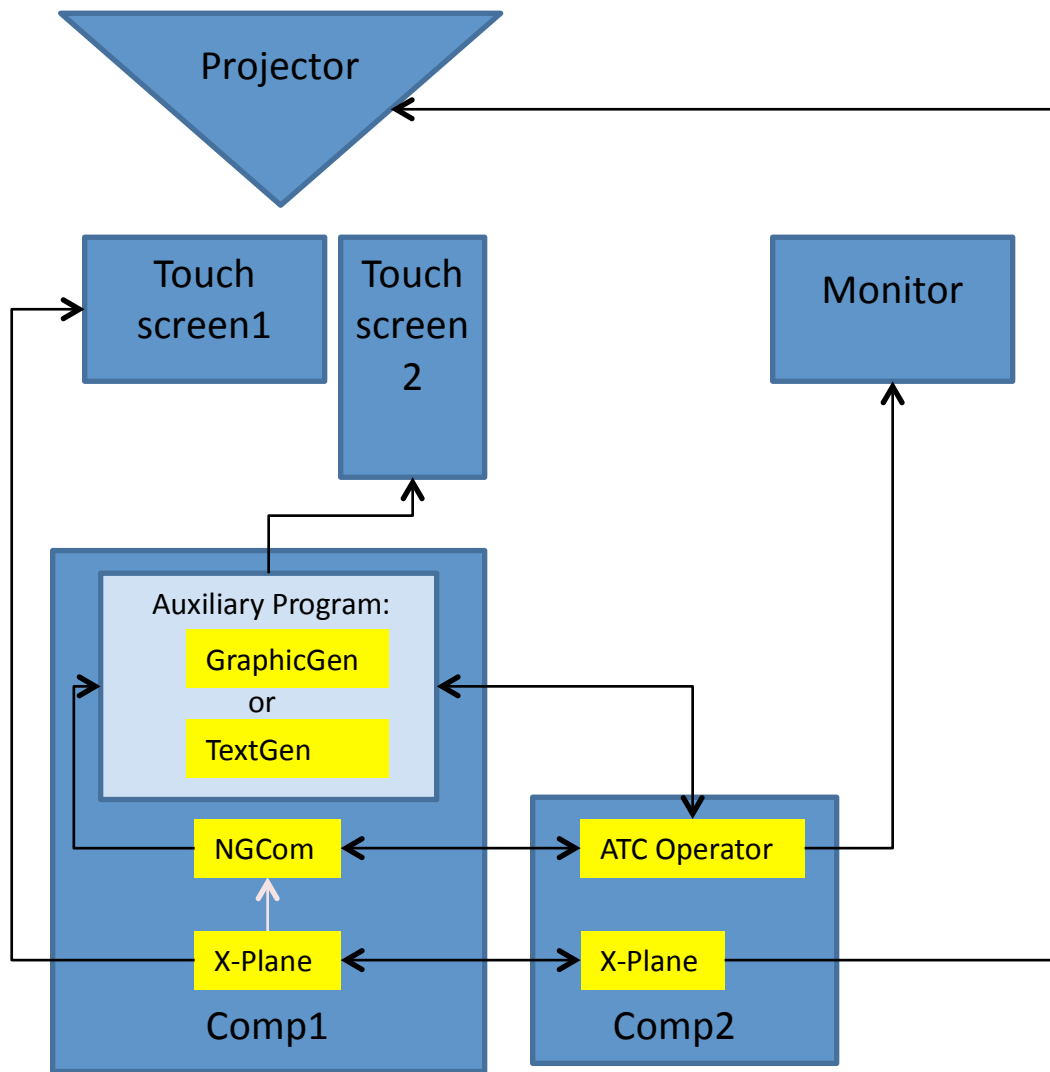
### **4.2. Subjects**

Twenty-four pilots volunteered to participate in this study. All 24 pilots were rated as Airline Transport Pilots (ATP), which included an instrument rating. Twenty-two of the pilots were male. Pilot average age was 46.8 years. The average flight hours was 10,125.

### **4.3. Apparatus**

#### **4.3.1. Hardware**

An overview diagram of the portable simulator hardware and software is presented in Figure 45. Each component is briefly described followed by a description of the DataComm Interface Software created for simulation.



**Figure 45. Diagram of the Portable DataComm HITL Simulator.**

#### 4.3.1.1. Computers

The two computers (Comp1, Comp2) are Cooler Master Storm Series Trooper (SGC-5000-KKN1) with ATX Full Tower Computer Case (Model:SGC-5000-KKN1). Each computer had an Intel motherboard (Model: GA-Z68XP-UD2P) and a GeForce GTX 530 Video Card (Model:015-P3-1582-A1). The processors were Intel Core i7-2700K Sandy Bridge 3.5GHz LGA 1155 95w Quad-Core with HD Graphics 3000 (Model:BX80623i72700K). The computers had 8GB of SDRAM. The computers were running using the Windows 7 Operating System.

Comp1 was used to run the flight control software, X-Plane 10, and sent information to the two touchscreen monitors viewed by the pilot. All flight control hardware (yoke, rudders, throttle) were connected to this computer. The pilot controlled the flight simulation through this computer. Comp1 also ran the custom software NGCom Plugin and the two auxiliary custom DataComm graphic interfaces. Comp1 was connected to Comp2 via a cross-over cable.

Comp2 also runs a copy of the X-Plane 10 software. This computer sent the “out the window scene” to an overhead projector to be displayed on a large screen in front of the pilot. This computer also controlled the customer ATC Operator Software.

#### **4.3.1.2. Displays**

The simulator had two Surface Acoustic Wave LCD touch-screen displays (Model Planar PT2275SSW). Display 1, placed in landscape mode directly in front of the pilot, was used to view and control the X-Plane aircraft cockpit controls. Display 2 was used in portrait mode and is located to the right of Display 1. It was used to view and interact with the custom DataComm interfaces during evaluations. A Standard Monitor (Samsung 2443BWT-TAA-1) was used to allow the experimenter to view and interact with the ATC Operator Software controlled by Computer 2.

#### **4.3.1.3. Projector and Screen**

The Projector was an Epson (Model G5450WUNL) 1920 x 1200 LCD project with an optional short throw lens. The projection screen was a DaLite Screen, Da-mat screen 84” x 52” which supports wide projection angles. Figures 46 – 48 are photographs of the hardware.



**Figure 46. Two Computers Next to the Simulator.**



**Figure 47. Two LCD Touch Screen Displays Inside the Cockpit. Yoke, Throttles and Flaps are also Visible.**



**Figure 48. DaLite Projection Screen and Epson Projector.**

### **4.3.2. Software**

#### **4.3.2.1. X-Plane 10**

X-Plane 10 is an off-the-shelf flight simulation software that provides the ability to build plugin programs that work in conjunction with the simulation. X-Plane ran in a synchronized mode on both computers.

#### **4.3.2.2. NGCom Plugin**

NGCom plugin was developed to allow communication between X-Plane Software and the custom DataComm Interface Software. This program also handled the transmission of information between X-Plane and the ATC Operator Software.

#### **4.3.2.3. ATC Operator**

ATC Operator was developed to simulate sending UMs to the DataComm Interface Software under evaluation, and to receive the DM messages sent by the pilot. The program included the following capabilities:

- 1) Ran premade scenario files to initiate flight plans, set X-Plane variables within X-plane software and in the DataComm Interface Software, and sent pre-set UMs automatically to the pilot.
- 2) Allowed a user to create a UM message in real-time during the simulation to communicate with the pilot.
- 3) The program sends and received all messages from the DataComm Interface Software.

#### **4.3.2.4. DataComm Interface Software 1: TextGen**

TextGen was developed to allow the pilot to view the current aircraft state on a ND, view the ATC clearances via graphics and text, and to allow the pilot to create DMs through the touchscreen interface.

Figures 49-50 illustrate the TextGen Interface. Figure 49 shows a dynamic ND in the left window that is controlled using X-Plane. The graphic portrayed the current flight path in Magenta. The window to the right containing text in green was the area where text clearances were received. When a text clearance was received it was also drawn on the ND. The concepts for the graphics on the ND are the same as those used in DC-MAT. Two buttons become available once a clearance is received: WILCO and UNABLE.

#### **4.3.2.5. Flight Planning Software**

Goodway (Version 4), a flight planning software tool, was utilized to develop flight scenarios. Flight plans considered type of aircraft to estimate fuel burn, weight, and time between waypoints. The simulated aircraft was a Boeing 777. All the flights were created within the continental United States. The FMS flight plan was exported and transferred to the simulator housing X-plane for input to the FMS.

#### 4.3.2.6. Software Programming

The simulator was built using JAVA 7.7 in the Netbeans IDE environment (Version 7.1.1)

### 4.4. Stimuli

#### 4.4.1. Clearances

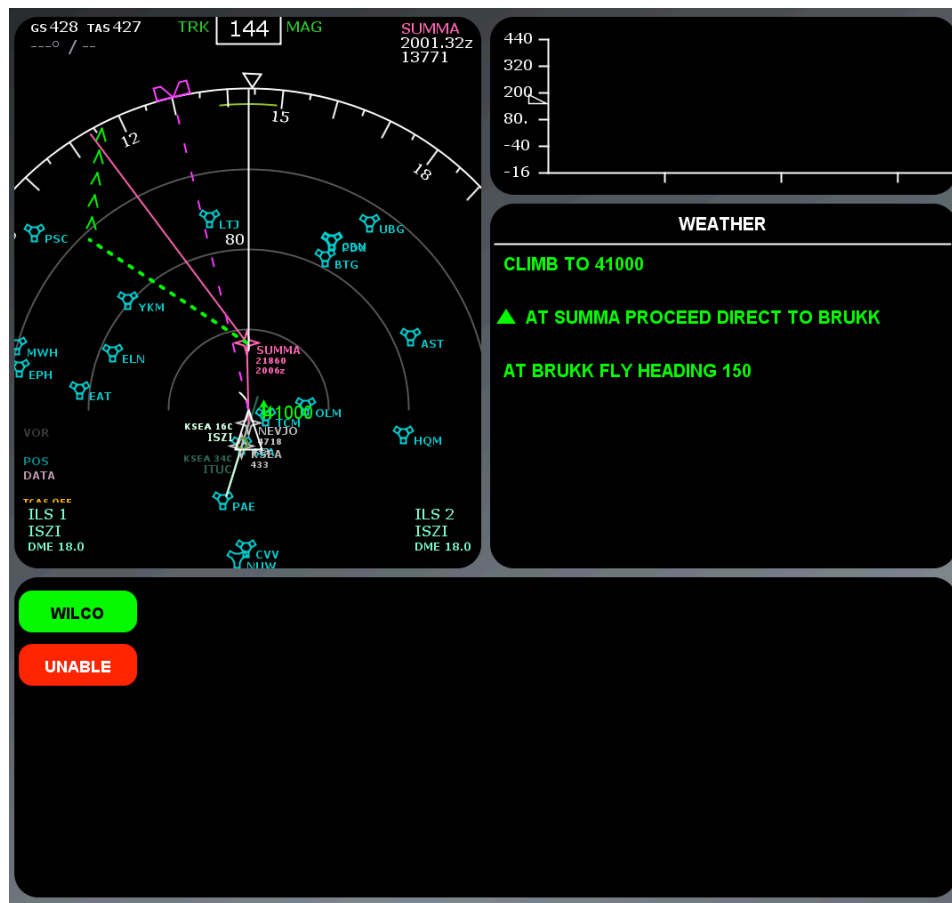
There were ten separate clearances. Each of the ten clearances was presented four times to the pilot (40 clearances). Two of the four clearances were designed such that the pilot should accept the clearance. Two of the four clearances were designed such that the pilot should reject the clearance. Table 16 lists the 10 clearances. There were a total of twenty flight paths used to present the 40 clearances. The 20 separate flight scenarios were authentic and the ND provided information about airports, VOR (Very high frequency Omni-directional Range) stations, NDB (Non-Directional Beacons), and Waypoints.

**Table 16. Ten Clearances Used for Experiment II.**

UM Numbers	Clearance Text
<b>Three Element Clearances</b>	
UM23, UM77	DESCEND TO [level]. AT [positionR] PROCEED DIRECT TO [positionR].
UM64, UM68	OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position ATW]
<b>Four Element Clearances</b>	
UM27, UM339	CLIMB TO REACH [level] BEFORE PASSING [position ATW]. AT [positionR] CLEARED TO [positionR] VIA [route clearanceR]
UM25, UM78	AFTER PASSING [position ATW] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [positionR]
UM28, UM76	DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position].
UM65, UM68	AT [position ATW] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position ATW]
UM188, UM97	AFTER PASSING [position ATW] MAINTAIN [speed]. AT [position] FLY HEADING [degrees].
UM46, UM310	CROSS [positionATW] AT LEVEL [level]. AT LEVEL [level single] MAINTAIN [speed]
<b>Five Element Clearances</b>	
UM23,UM77, UM97	DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].
UM76, UM339	AT TIME [time] PROCEED DIRECT TO [position]. AT [positionR] CLEARED TO [position] VIA [route clearanceR]

#### 4.4.2. TextGen Interface for Creating DMs

One of the two interfaces developed for this evaluation was named TextGen. The TextGen interface provided pilots with an additional ND that emulated the primary ND, and was depicted on the upper left window of the screen (see Figure 49). The ND display provided a graphic of the current flight path and the ATC clearance via graphics. The ATC clearance was also presented as Text in the second window on the right. The top window was included for tests of the ASD described in Experiment I, but was not used for this study. Beneath the ND is a window that included a WILCO or UNABLE button. When a clearance was received from the simulated ATC station, the pilot interpreted the text and graphic of the clearance, and selected the option WILCO or UNABLE.

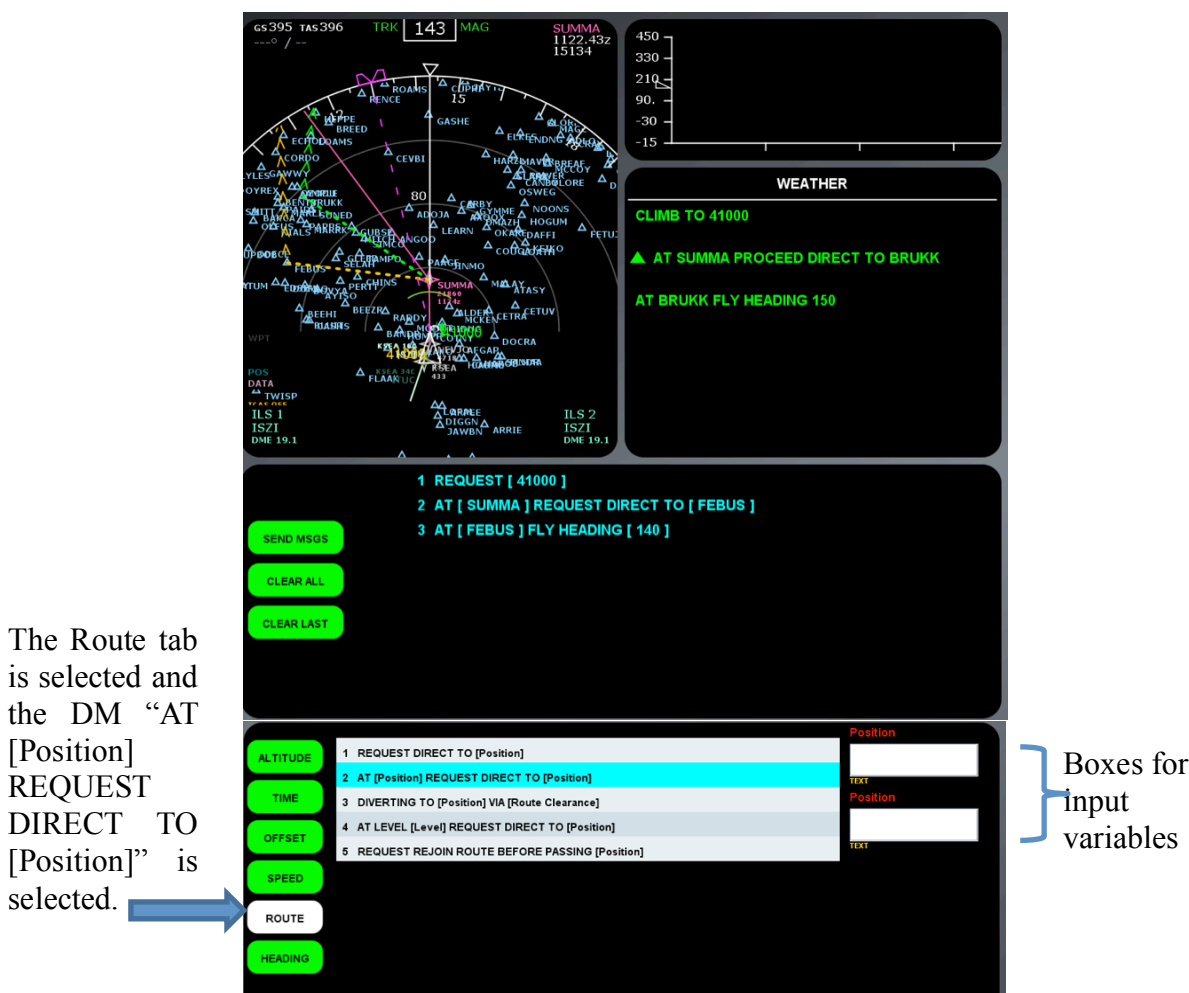


**Figure 49. Screen Shot of TextGen with ND and Clearance.** (Note only VOR stations are currently selected as overlay so the waypoint is not visible.)

If WILCO was selected, the screen cleared and the flight continued. If the pilot chose UNABLE, the bottom part of the screen, changed and provided the capability to request a clearance using DMs (See Figure 49). Text categories for DM messages were listed. The pilot selected a category and the information expanded on the screen to list the DM message. Once a message was selected, boxes opened to the right for variable input. For example the word “position” was



provided over the box. The variable word was presented in RED (see Figure 50), but changes to green after the waypoint was added by the pilot. An “Accept” button also appeared in the window above the text DM categories. After the pilot entered the DM they were required to enter “Accept” which would then draw the DM message on the ND display using graphics in orange. The pilot followed this sequence to concatenate other DMs. Once a DM was accepted, the DM text turned aqua and the pilot could review the text message and the ND graphic before choosing “Send MSGS”. The entire concatenated message was sent to the simulated ATC station. The system recorded response times, DM creation times, and the concatenated message the pilot created.



**Figure 50. Screen Shot of TextGen with Categories for Selecting DMs.** (The Pilot has Accepted the Three DMs Listed Under the ND.)

#### 4.5. Procedures

The flight simulator and simulated ATC were portable and placed in a hanger at Cessna in Wichita, Kansas for eleven days. Volunteer pilots were provided with an informed consent and were trained with 4 practice trials (8 clearances) to become familiar with the interface and rules

for WILCO (accepting) or UNABLE (rejecting) based on the scenarios. The basic rules for rejecting or accepting a clearance are listed in Table 17 below.

**Table 17. Rules for Unable and WILCO.**

	Rules for Rejecting	Rules for Accepting
Position	If the clearance does not bring you back onto your original route. And/or an offset is greater than 30 nautical miles.	Route changes brings aircraft back to original flight path. Intersects, proceed direct to a position on the flight path, offsets less than 30 nautical miles and brought back to flight path.
Altitude	Clearances that direct you to climb to an altitude you are already above or descend to an altitude you are already below.	Altitude seems correct given current altitude.
Heading	Heading does not eventually intersect with original flight plan	Heading intersects your original flight path.
Time	If clearance requires to re-route or change altitude at a specific time and time is not accurate.	Time is acceptable given current speed and time.
Speed	Speeds that would be too slow based on position, altitude, or phase of flight.	Speed is acceptable based on flight position, or type of plane.

Pilots participated in the experiment for approximately two hours. The scenarios were randomized for each subject. Upon completion of the experiment the pilots were debriefed and thanked for their participation.

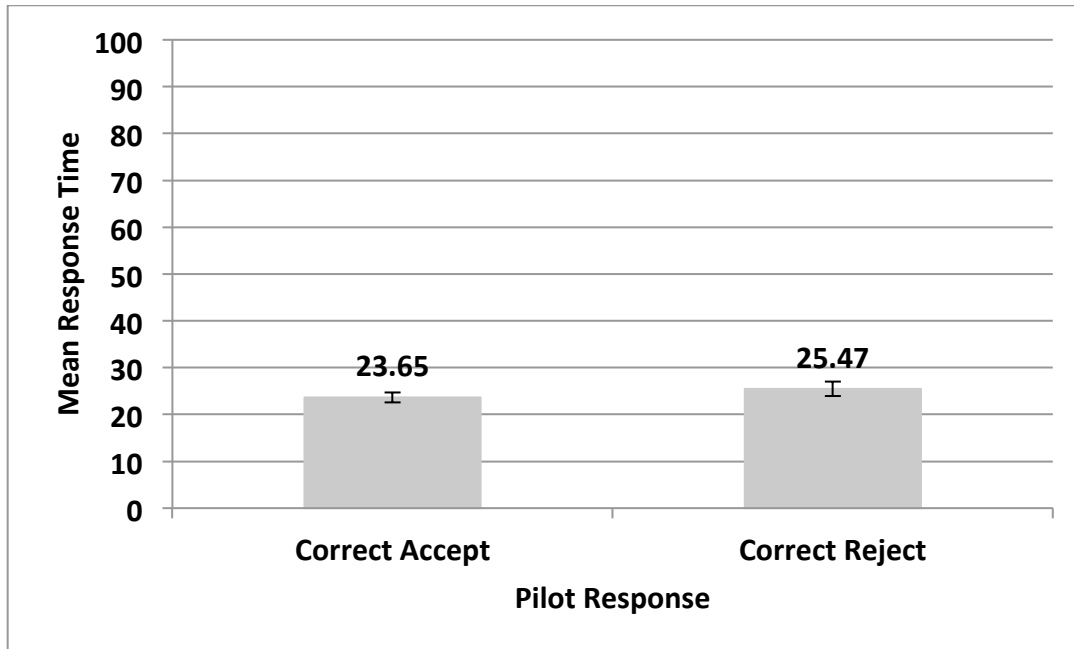
#### **4.5.1. Results**

The raw data were imported into excel files and descriptive statistics were calculated using JMP Pro 10.0.1 Release 2. The mean response time and mean percent correct were calculated along with standard deviation, variance, standard error, and confidence intervals. Response time data are skewed to the left, which is common for response time measures. The results are presented below.

##### **4.5.1.1. Mean Response Time**

##### **4.5.1.1.1. Response Time for Correct Accepts and Correct Rejections**

Figure 51 presents the mean response time and standard error bars for correctly accepting and rejecting a clearance. Both times were very similar. The standard deviation is high. Table 18 Summary statistics are presented in Table 18.



**Figure 51. Mean Response Time for Correct Accepts and Correct Rejections.**

**Table 18. Summary Statistics for Mean Response Time for Correct Accepts and Correct Rejections.**

Level	Number data pts	Mean	Std Dev	Std Err	Lower 95%	Upper 95%	MIN	MAX
Correct Accept	322	23.931	19.70	1.10	26.09	21.78	2.9	115.83
Correct Reject	364	25.47	29.02	1.52	22.47	28.46	2.59	178.72

#### **4.5.1.1.2. Mean Response Time to Create a DM**

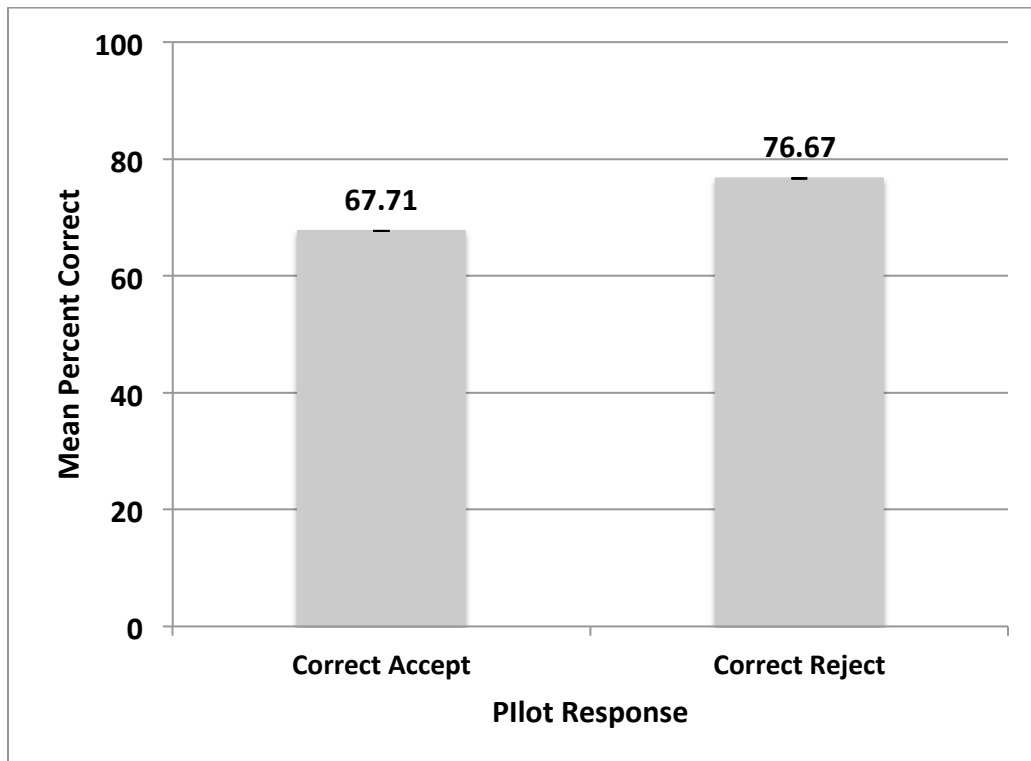
Table 19 provides summary statistics for MRT to create a DM using TextGen. There were three outliers that had excessive response times that were removed. These three outlying data points are possibly due to the pilots discussing the interface during the task. On average it took approximately one minute and twenty-two seconds to create a DM. The longest response time was six and one-half minutes. The standard deviation is high, most likely due to the complexity of different types of clearances.

**Table 19. Summary Statistics for Mean Time to Create a DM.**

<b>Number Data Pts</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Std Err</b>	<b>Lower 95%</b>	<b>Upper 95%</b>	<b>Min</b>	<b>Max</b>
343	82.99	42.23	2.28	78.50	87.47	4.88	249.71

#### **4.5.1.2. Mean Percent Correct**

Figure 52 presents the mean percent correct accepts and mean percent correct rejections. Similar to Experiment I, pilots correctly reject clearances with more accuracy than accepting them. The standard deviation is large (46.81%). Table 20 summarizes the statistics for these data.



**Figure 52. Pilot Mean Percent Correct For Accepts And Rejections.**

**Table 20. Summary Statistics for Mean Percent Correct Accept and Correct Rejections.**

		Pilot Answer	
		Accept	Reject
Correct Answer	Accept	67.71 % Std Dev 46.81 Std Error 02.14 CI: 63.51 and 71.91 N = 480	32.29 %
	Reject	23.33 %	76.67 % Std Dev = 42.34 Std Error = 01.93 CI: 72.87 and 80.46 N = 480

#### 4.5.2. Pilot Comments

- For Experiment II “AT POSITION FLY HEADING” (UM97) was presented after “PROCEED DIRECT TO POSITION” pilot had no issue with this structure. In Experiment I many pilots stated that currently they never receive a route clearance after “PROCEED DIRECT TO POSITION” (UM74). In Experiment I “FLY HEADING” (UM190) was sometimes placed after “PROCEED DIRECT TO POSITION” and many pilots had issues with this clearance structure on the static experiment.
- The concatenated clearances were not always well accepted by pilots because they were not similar to current practice with voice. Voice clearances are usually one or two element messages requiring immediate execution. Therefore, there is little ambiguity about when to begin executing. UMs were concatenated together and some sections of the clearance were meant to be executed sequentially, that is, later in time or position. Each pilot had a unique perspective on DataComm based on their experience
- Pilots communicated that the cardinal rule when it comes to aviation is: Aviate > Navigate > Communicate. The priority is to safely fly the plane. In traffic or weather conditions they will always follow this protocol and worry about negotiation with ATC when possible. This ideology especially applies if a complex concatenated message is sent to a pilot just before they are expected to begin the execution of the clearance. Pilots want ample time to first understand the clearance, and if they need to reject it, time to create their response to ATC. Minimal input to create DMs was requested by all pilots. This point could not be stressed enough.

- Pilots liked that the DM was supplied for them when creating the DM to ATC once they rejected the initial clearance. They liked only having to input the variables for each message, rather than having to type the entire message.
- Pilots appreciated that the original text clearance remained on the screen for reference while they constructed the DM.
- Most pilots felt that there was a learning curve to the interface, but once they adapted to what they were expected to do, and rules for accepting or rejecting a clearance, their confidence with the interface increased.
- Pilots indicated that if a clearance did disappear once 'WILCO' was selected it would be an issue if they were expected to actually carry out the clearance upon acceptance. They stated that it would be vital to have the clearance remain within a log for reference..
- Pilots did not like the number of button presses required to interact with the interface to create a DM.
- Pilots did not like having to "Accept" each downlink message (DM) when concatenating DMs. The graphics for the DM was drawn after pilots selected the accept button. This increased the number of inputs. If pilots forgot to accept each message, the message was removed. The graphic should be created as they complete each variable with fewer inputs.
- Many pilots did not like the virtual Qwerty keypad because they typically used a letters in order alphabet keypad. However, some pilots indicated they had recently adapted to using an iPad to access maps and perform navigation, so felt the keypad was not an issue.
- The experimental instructions were to reject the entire clearance even if only one part of the clearance was incorrect. Pilots had to create a request to reconstruct the entire message, correcting the variables they disagreed with. This is the way they "negotiated" with ATC. Pilots commented that they would prefer being able to accept parts of the clearance, and only fix sections that were incorrect. This was primarily due to the number of inputs necessary to recreate clearance and the possibility of introducing errors.
- There was no error checking in the experimental system. If a waypoint was spelled incorrectly they were not prompted. Pilots expected the system to ensure they did not make such a mistake.
- When the pilot needed to make an input, the keypad that was displayed only had keys that were relevant. For numerical input, a number pad displayed. For the alphabet, a Qwerty keypad displayed. Pilots liked this idea. When waypoint inputs were required both keypads were displayed. Pilots commented that only the Qwerty keypad should be available for waypoints. Both were included based on the idea that lat/long may be an input for TBOs in the Next Gen Air Space.

- The SC-214 text for DMs is not identical to the text in a UM. When pilots attempted to create a DM from a list of possible DMs using the TextGen Interface, the text of the DM did not directly match the UM to which the pilot was responding. Table 21 shows the UMs used in the evaluation and which DMs were paired as a response to the UM messages. The text is slightly different, but the context of the messages remains consistent.

**Table 21. Uplink and corresponding downlink messages used in Experiment II and III.**

UM #	Uplink Messages (UMs)		Downlink Messages (DMs)	DM #	Notes
20/23	CLIMB TO [level] / DESCEND TO [level]	<i>translates to . . .</i>	REQUEST [level]	6	Issue
46/25/27	CROSS [position] AT LEVEL [level] / AFTER PASSING [position ATW] DESCEND TO [level] / CLIMB TO REACH [level] BEFORE PASSING [position]	<i>translates to . . .</i>	AT [position] REQUEST [level]	11	Big Issue
78	AT LEVEL [level single] PROCEED DIRECT TO [position]	<i>translates to . . .</i>	AT LEVEL [level] PROCEED DIRECT TO [Position]	x	Fiction
28	DESCEND TO REACH [level] AT OR BEFORE TIME [time]	<i>translates to . . .</i>	AT TIME [time] REQUEST [level]	13	No Problem
76	AT TIME [time] PROCEED DIRECT TO [position]	<i>translates to . . .</i>	AT TIME [time] PROCEED DIRECT TO [Position]	x	Fiction
64	OFFSET [specified distance] [direction] OF ROUTE	<i>translates to . . .</i>	REQUEST OFFSET [specified distance] [direction] OF ROUTE	15	No Problem
65	AT [position] OFFSET [specified distance] [direction] OF ROUTE	<i>translates to . . .</i>	AT [Position] REQUEST OFFSET [specified distance] [direction] OF ROUTE	x	Fiction
		<i>translates to . . .</i>	REQUEST HEADING [degrees]	70	Not appropriate in exp

UM #	Uplink Messages (UMs)		Downlink Messages (DMs)	DM #	Notes
97	AT [position ATW] FLY HEADING [degrees]	<i>translates to . . .</i>	AT [Position] FLY HEADING [Degrees].	x	Fiction
		<i>translates to . . .</i>	REQUEST DIRECT TO [position]	22	Not appropriate in exp
77/339	AT [position] PROCEED DIRECT TO [position] / AT [position] CLEARED TO [position] VIA [route clearance enhanced]	<i>translates to . . .</i>	AT [position] REQUEST DIRECT TO [position]	119	Used back to back in DM at times
		<i>translates to . . .</i>	DIVERTING TO [position] VIA [route clearance]	59	Not advised to use
68	REJOIN ROUTE BEFORE PASSING [position]	<i>translates to . . .</i>	REQUEST TO REJOIN ROUTE BEFORE PASSING [Position]	x	Fiction
		<i>translates to . . .</i>	REQUEST [Speed]	18	Not appropriate in exp
188	AFTER PASSING [position] MAINTAIN [speed]	<i>translates to . . .</i>	AT [Position] REQUEST [Speed]	x	Fiction
310	AT LEVEL [level single] MAINTAIN [speed]	<i>translates to . . .</i>	AT [LEVEL] REQUEST [Speed]	x	Fiction

- The experiment was conducted with single seat pilots. Pilots stated that the plane would have to be on autopilot or it would be difficult to interact with the interface and fly safely and smoothly.
- Pilots liked having the additional ND to interact with when they created DMs. They thought that once ATC and pilots agreed on the clearance, the graphic could be loaded into the ND next to the primary flight display (PFD).
- Most UMs and DMs do not specify the units of measure because they are considered to be part of the text. For example, UM 310: After passing [position] maintain [speed].



When creating DMs, pilots did not necessarily know that 300 meant 300 Knots (although it specifically stated 'knots' on the graphic ND). When they tried to create a DM to change the value there was a misunderstanding of the unit, thus pilots choose a category for the DM unrelated to speed. The DM message becomes irrelevant. Many pilots assumed 300 was an altitude, referring to a specific flight level.

- The touch screen was not optimized for human use with respect to placement and hand or arm fatigue. This was noted by pilots. If touchscreens are used they must be placed in a usable position based on the interface design. Future research should address this issue and recommendations should be developed.
- Many pilots stated that the graphics for reviewing the clearances were very useful for conveying the intent of the concatenated text clearance. When creating a DM that required a route or heading change, pilots commented that a graphic of the DM was needed to support their ability to confirm the DM before sending to ATC. They did not think it was necessary to see the numbers for speed, altitude, or time on the graphic. Before removing information from the ND based on these comments, additional research should be conducted.

#### **4.5.3. Summary Discussion of Experiment II**

The exploratory study for evaluating DM creation provided input to the human factors recommendations found in Volume I. Response time for accepting a clearance were longer than rejecting a clearance, which was also noted in Experiment I. Note that the graphics are the same as those used in Experiment I under the G+T and G+T+updUM condition. However, this study used a dynamic simulator and pilots were also evaluating their flight. The flight was on autopilot and no anomalies were interjected.

With respect to mean percent correction accepts and rejections pilots correctly rejected clearances at a higher rate then accepting them. These data are also similar to experiment I. Pilots were very conservative and tended to reject more clearances than accept them, even if our definition was to accept. They may be thinking of other considerations from their experience when making the decision and that information was not necessarily reflected in the scenarios.

There were aspects of TextGen interface that pilots liked. However, due to the use of an experimental simulator some aspects of the software development interfered with response time. For example, in order to draw the DM, pilots had to select a button on the screen before moving on to the next concatenated DM. There were too many inputs required. However, many of the drawbacks they mentioned can be fixed and concepts were written into the recommendations.

## **5. Method Experiment III. Interacting with graphics as an alternative to text for downlink messages.**

Graphic interaction techniques have expanded as hand-held phones and tablets have hit the market. Many devices, including tablets are being used in aircraft. These new techniques are likely to be designed into flight decks. To continue with the evaluation of text and graphics an interface was designed called GraphicGen, which included hybrid text and graphic combinations for displaying clearances and included the ability to create DMs by interacting with the graphics. Experiment III compared performance using GraphicGen and TextGen.

TextGen was slightly modified to be a text only DM creation interface. For this experiment the clearance was presented with text and graphics, but when pilots created the DM, they could only review the concatenated text. In other words, the DM was not drawn on the ND as it was in Experiment II.

### **5.1.1. Hypotheses**

While the expectation is that GraphicGen will improve performance, it is possible that graphic designs could hinder performance, therefore the null hypotheses are stated as two tail tests:

- 1) There is no difference in mean response time to correctly accept a clearance between TextGen and GraphicGen. (Expected: No difference because both interfaces have same presentation of text and graphics for presenting clearances).
- 2) There is no significant different in mean response time for creating a DM between TextGen and GraphicGen. (Expected: GraphicGen will result in faster responses).
- 3) There is no significant difference of percent correct interpretation between TextGen and GraphicGen (Expected: No difference because both interfaces have same presentation of text and graphics for presenting clearances).

### **5.1.2. Experimental Design and Independent Variable**

The experimental design was a single factor between-subject design with one IV, Presentation Format. The two levels of format were TextGen and GraphicGen. The differences between these techniques are described under Stimuli.

### **5.1.3. Dependent Variables**

The DVs included the following:

- 1) Mean response time to correctly accept a clearance.
- 2) Mean response time to correctly reject a clearance combined with time to create a DM.
- 3) Percent correct accept and percent correct rejections.

### **5.1.4. Subjects**

Eight pilots from Dayton, Ohio near Wright State University volunteered to participate in this study. All 8 pilots were instrument rated. Seven of the eight were male and the average age was 48.6 years. The average number of flight hours was 3,462.

### 5.1.5. Apparatus

The simulator described in Experiment II (Section 4.3) was also used for this study.

### 5.1.6. Stimuli

#### 5.1.6.1. Clearances

This study used six of the ten clearances and scenarios that were used in Experiment II. The six clearances were repeated four times resulting in 24 clearances for each interface condition (TextGen vs. GraphicGen). Half of the clearances were designed such that the pilot should respond UNABLE. Half were designed so the pilot should respond WILCO. Three clearances were placed within one of 8 flight scenarios. Table 22 lists the 6 clearances. The 8 separate flight scenarios were authentic and the ND provided information about airports, VOR (Very high frequency Omni-directional Range) stations, NDB (Non-Directional Beacons), and Waypoints.

**Table 22. Six clearances used during Experiment III.**

UM Numbers	Clearance Text
<b>Four Element Clearances</b>	
UM188, UM97	AFTER PASSING [position ATW] MAINTAIN [speed]. AT [position] FLY HEADING [degrees].
<b>Five Element Clearances</b>	
UM27, UM339	CLIMB TO REACH [level] BEFORE PASSING [position ATW]. AT [position] CLEARED TO [position] VIA [route clearanceR].
UM20, UM77, UM97	CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].
UM76, UM339	AT TIME [time] PROCEED DIRECT TO [position]. AT [positionR] CLEARED TO [position] VIA [route clearanceR]
UM25, UM78, UM97	AFTER PASSING [position ATW] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [positionR]. AT [position] FLY HEADING [degrees]
<b>Six Element Clearances</b>	
UM28, UM76, UM97	DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]

#### 5.1.6.2. TextGen Interface for Creating DMs

The TextGen interface was identical to the interface described in Experiment II (Section 4.4.2). The only difference was that when pilots created a DM, the graphic of the DM was not shown in orange on the ND.

#### 5.1.6.3. GraphicGen Interface for Creating DMs

The GraphicGen interface was designed as a drag and drop interface using a touch screen. Instead of using categories and text to create the DM, the pilot was able to move the graphics on the ND to create the DMs. The DM was then automatically created as Text so that the pilot could read the text DM before accepting the message. Figures 53-55 illustrate the basic interface from arrival of a clearance through creation of the DM. Figure 53 illustrates the basic interface after receiving a clearance from the simulated ATC. A magenta line showed the aircraft's current flight path. The green line was the clearance instruction presented graphically while the text clearance was presented in green in the window to the right of the ND.

If a pilot chose UNABLE, the ND graphics updated with an orange line drawn on top of the green line. In the window below the ND, an orange DM text message was automatically created that matched the clearance. The pilot could select different portions of the orange line or text on the graphic (such as altitude) using their finger. They could then drag the line, or input new values into variables, such as altitude (Figure 54 and 55).

Figure 53 illustrates that the pilot has requested to go to LTJ via AST, BTG. As the pilot moved the line to a VOR or other waypoint on the ND, the system would automatically lock onto the nearby VOR or waypoint. The orange text showed when the waypoint was selected so the pilot could release the line. If there is no VOR or waypoint and the pilot releases the line, the system would calculate the Lat/Long of the new waypoint and put that in the DM text. It must be noted that for this experiment the concept was to create a DM based on the clearance. It was not possible to create a DM that would add a variable that was completely different than those in the original clearance. For example, if the pilot wanted to concatenate the message with a speed request, it would not be possible unless speed was in the original clearance. A hybrid approach between TextGen and GraphicGen would be needed to create this flexibility.

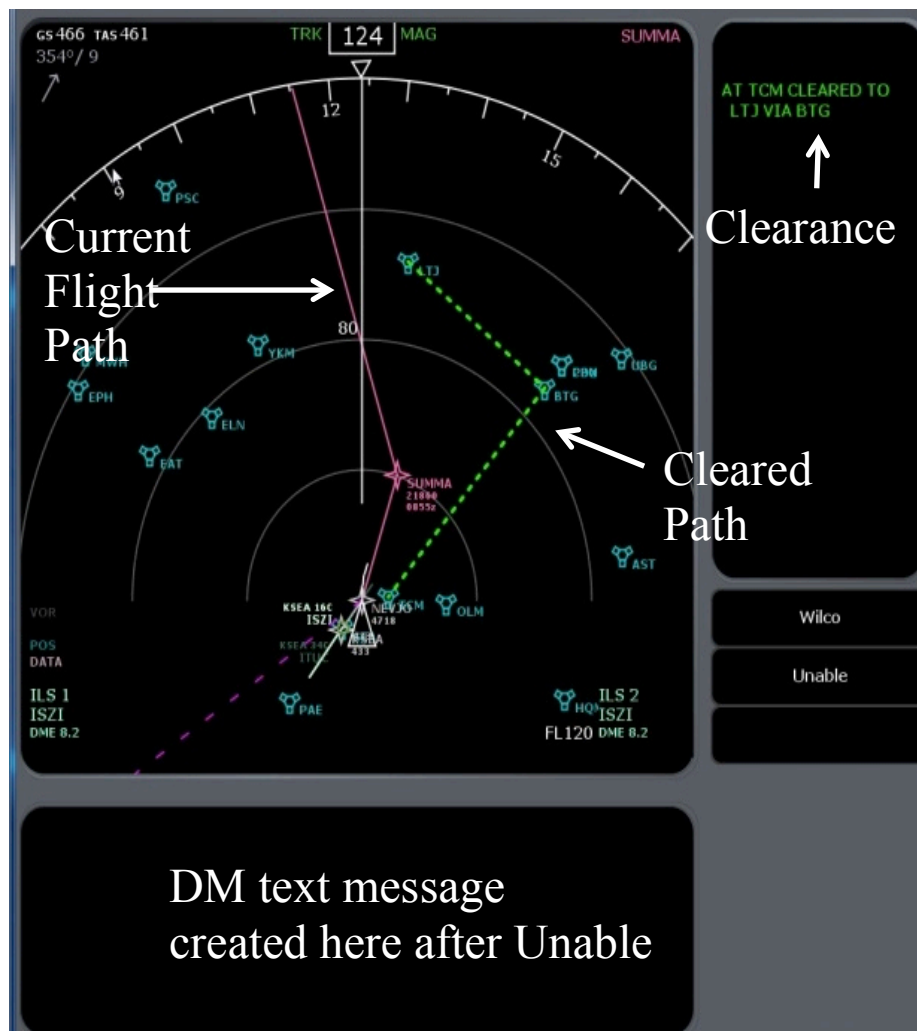


Figure 53. GraphicGen Drag and Drop Interface After Clearance Has Been Received.

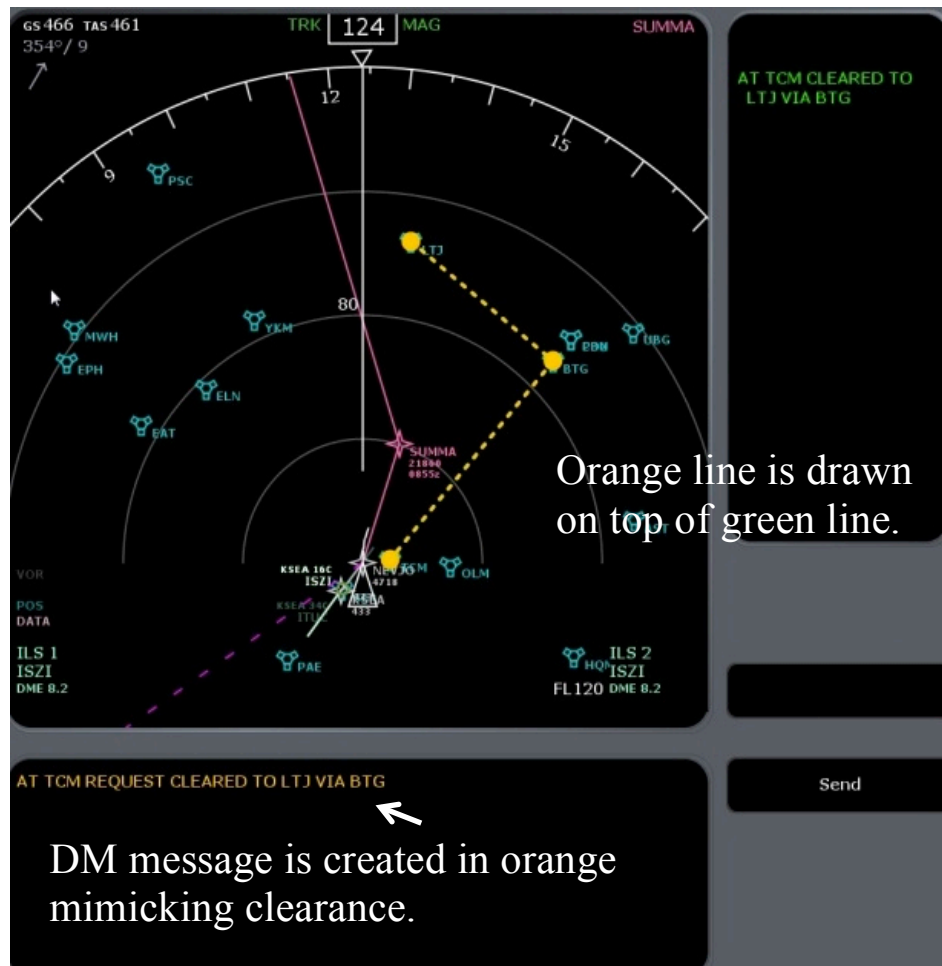
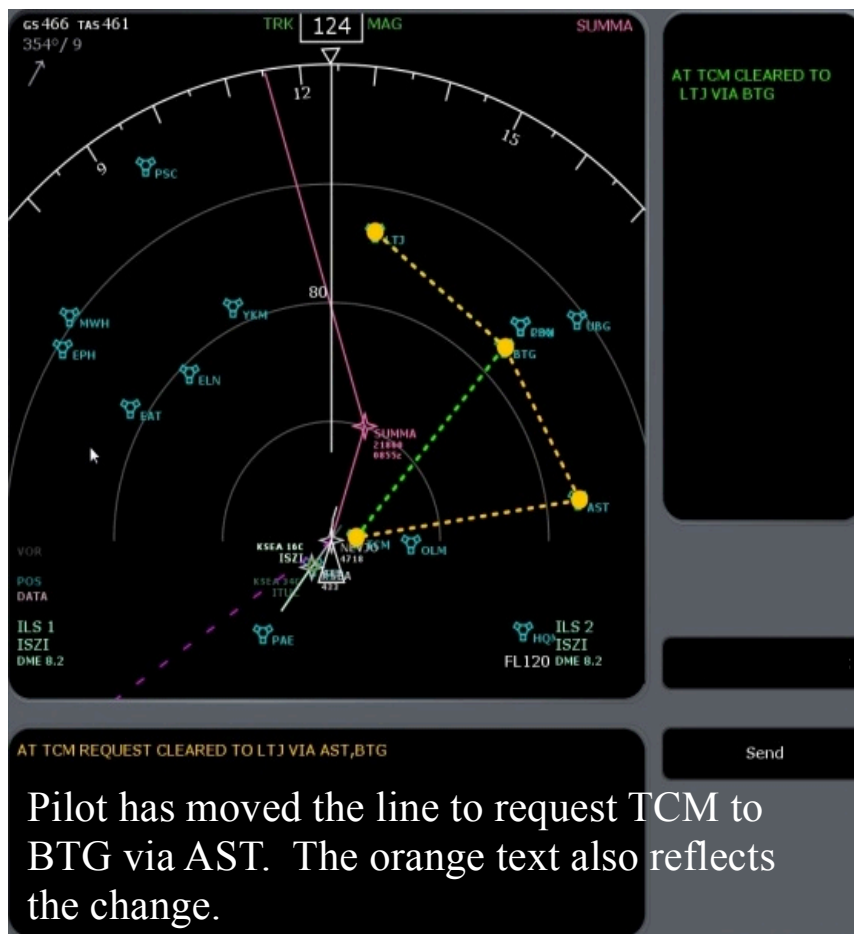


Figure 54. GraphicGen After the Pilot Selects Unable.



**Figure 55. GraphicGen After the Pilot has Moved the Orange Line to a New Waypoint. Orange text shows new DM.**

### 5.1.7. Procedure

Pilots were provided with an informed consent. Subjects participated in TextGen first followed by NextGen. Pilots were trained using two practice trials, which included six clearances in the practice scenarios showing every clearance possibility before they used each interface. They were also provided the rules for WILCO or UNABLE answers. The basic rules for rejecting or accepting a clearance are listed in Table 9 under Experiment II.

Upon completion of training subjects participated in the experiment for approximately two hours. For each interface the scenarios were randomized for each subject. Upon completion of trials, pilots shared their opinions about the interfaces. They were then debriefed and thanked for their participation.

### 5.1.8. Results

The raw data were imported into excel files and descriptive statistics were calculated using JMP Pro 10.0.1 Release 2. The mean response time and mean percent correct were calculated along with standard deviation, standard error, and confidence intervals. Response time data are skewed to the left, which is common for response time measures. To evaluate response time between

TextGen and GraphicGen a non-parametric test was run (Kruskal-Wallis One-Way ANOVA) because the data are not normally distributed.

#### 5.1.8.1. Mean Response Time

##### 5.1.8.1.1. Mean Response Time to Correctly Accept a Clearance

Figure 56 presents the mean response time to correctly accept a clearance. The Kruskal-Wallis test was statistically significant at  $p \leq 0.001$ . TextGen resulted in significantly slower response times to correctly accept a clearance than GraphicGen. Table 23 lists the summary statistics.

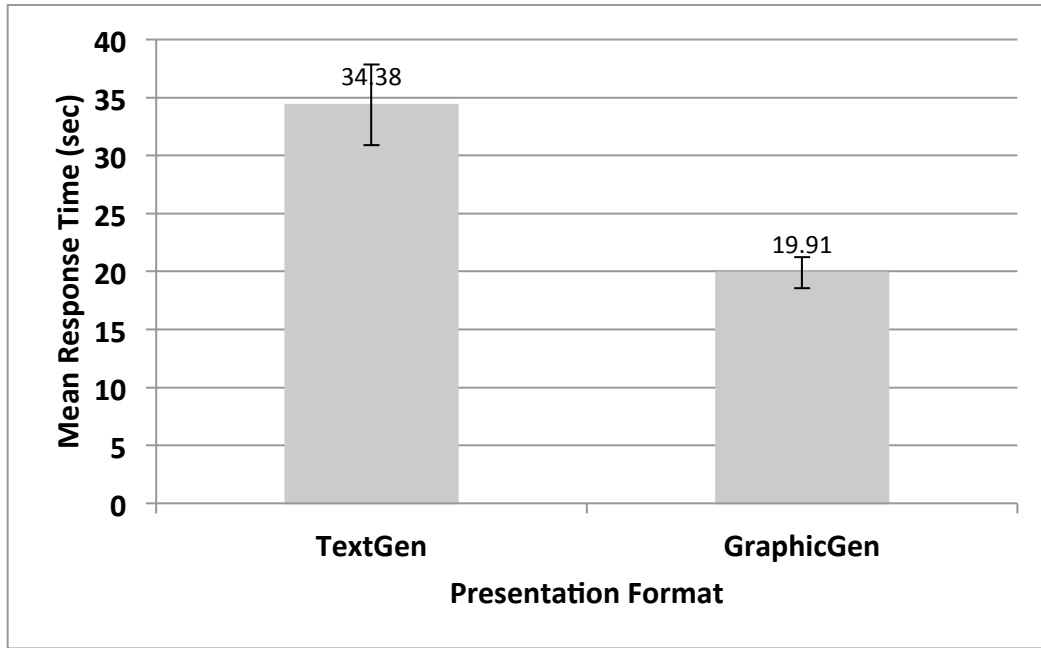


Figure 56. Mean Response Time for Correct Accept for TextGen and GraphicGen.

Table 23. Summary Statistics for Mean Response Time for Correct Accept as a Function of Presentation Format.

Format	Number data pts	Mean	Std Dev	Std Err	Lower 95%	Upper 95%	MIN	MAX
TextGen	59	34.38	26.75	3.48	27.41	41.35	8.51	151.32
GraphicGen	74	19.91	11.61	1.35	17.21	22.60	7.79	69.64



#### 5.1.8.1.2. Mean Response Time to Create a DM

Figure 57 illustrates the MRT to create a DM for both Formats. The Kruskal-Wallis test was statistically significant at  $p \leq .0001$ . Pilots using GraphicGen were able to create a DM in significantly less time than when using TextGen. Table 24 presents the summary statistics for both formats.

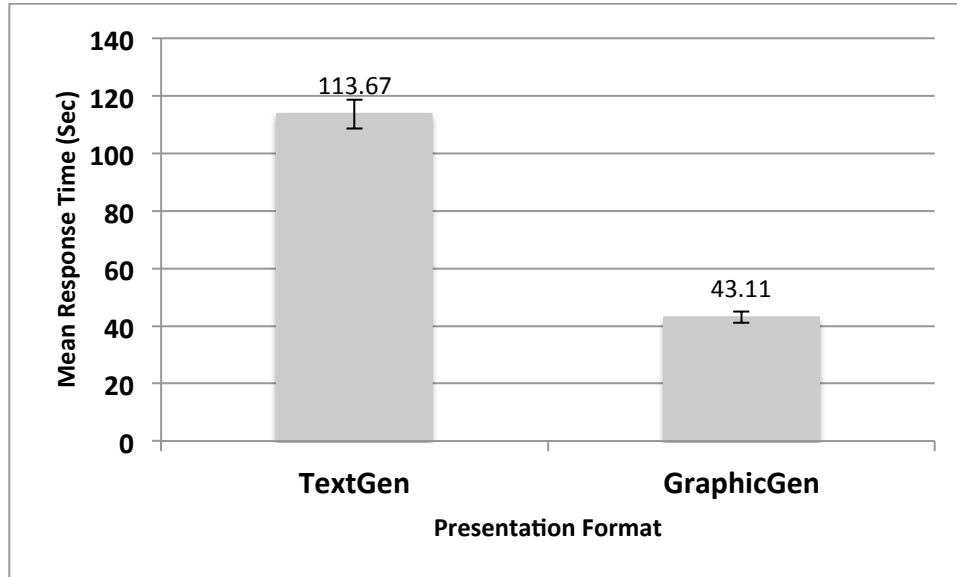


Figure 57. Mean Response Time to Reject a Clearance and Create a DM.

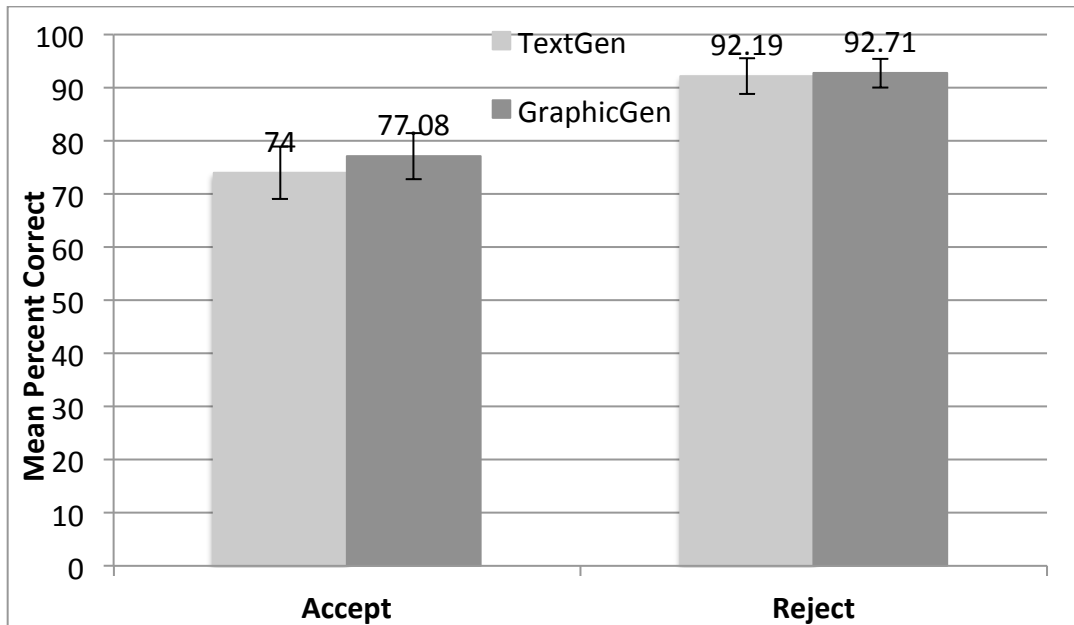
Table 24. Summary Statistics for Mean Response Time to Reject a Clearance and Create a DM.

Format	Number data pts	Mean	Std Dev	Std Err	Lower 95%	Upper 95%	MIN	MAX
TextGen	57	113.67	38.27	5.07	103.51	123.82	49.00	232.00
GraphicGen	88	43.11	18.72	2.00	39.15	47.08	13.00	105.00

#### 5.1.8.2. Mean Percent Correct

##### 5.1.8.2.1. Mean Percent Correct to Accept or Reject a Clearance.

Figure 58 illustrates the mean percent correct accepts and rejects for TextGen and GraphicGen. Table 25 presents the summary statistics. The Kruskal-Wallis test was conducted for Accept Corrects and Accept Rejects. There were no significant differences between TextGen and GraphicGen for Correct Accepts,  $p = 0.06094$ , nor Correct Rejects,  $p = 0.91$ . Pilots correctly rejected clearances with fewer errors than correctly accepting them.



**Figure 58. Mean Percent Correct Accepts and Rejections as a Function of Presentation Format.**

**Table 25. Summary Statistics for Mean Percent Correct Accepts and Correct Rejections as a Function of Presentation Format.**

		Pilot Answer			
		Accept		Reject	
		TextGen	GraphicGen	TextGen	GraphicGen
Correct Answer	Accept	Mean = 74.00 % Std Dev= 44.28 Std Error= 4.95 CI: 63.90 & 83.60 N = 80	Mean = 77.08% Std Dev = 42.25 Std Error = 4.31 CI: 68.52 & 85.64 N = 96	Mean = 26 %	Mean = 48.92 %
	Reject	Mean = 7.81 %	Mean = 7.29 %	Mean = 92.19 % Std Dev = 27.05 Std Error = 3.38 CI: 85.43 & 98.94 N = 64	Mean = 92.71% Std Dev = 26.13 Std Error = 2.7 CI: 87.41 & 98.00 N = 96

### **5.1.9. Pilot Comments**

- All eight pilots stated that the graphic-based interface (GraphicGen) was better than the text-based interface. Pilots liked that the DMs were automatically created once the clearance was rejected and that they only had to provide input for variables that were numeric.
- Pilots' thought that the manipulation of the graphic on GraphicGen was intuitive and liked that the text DMs updated in real time in conjunction with the graphics.
- Pilots appreciated that the system automatically locked onto a waypoint or VOR station as the graphics were manipulated. Once a waypoint was chosen using the graphic interface, the waypoint or VOR was added to the DM.
- For both TextGen and GraphicGen, pilots appreciated that the original clearance remained on the ND for reference.
- Pilots were concerned that turbulence could affect their ability to use a touch screen.
- The GraphicGen interface was designed to respond directly to incoming clearances. There was no ability to create a request unless it was a response to the clearance. Because they also used TextGen, they noted that GraphicGen would need the ability to create requests that were not based on the clearance. An interface that is a hybrid of TextGen and GraphicGen would be needed.
- Pilots were presented with 2 scenarios (6 different clearances) under the TextGen condition that provided graphics when creating the DM in order to compare the this capability to their experience of DM creation without graphics. All pilots stated that they would prefer to have the graphics because it would help them to check their request.

### **5.1.10. Discussion**

The results for this study showed that there was a significant difference between the mean number of correct accepts and correct rejections for both TextGen and NextGen. Pilots correctly rejected clearances with fewer errors than accepting them. These results are similar in all three experiments. There was no difference between TextGen and GraphicGen with respect to percent correct accepts or rejections. Where the difference becomes obvious is with response time. GraphicGen resulted in significantly faster response times to create a DM. The variance was lower for GraphicGen. The difference between means is approximately 71 seconds. Pilots also favored the GraphicGen approach when asked their opinions.

An interesting finding is the difference in response time to correctly accept a clearance. TextGen resulted in significantly slower response times than GraphicGen, yet the text clearance and ND graphics were similar between the two conditions. There were only two differences between the NDs. One difference was the size of the ND. For TextGen the ND was smaller at 15.25 cm high x 12.57 cm wide. For GraphicGen the ND took up most of the interface at 18.10 high x 18.41 wide. The second difference was the WILCO and UNABLE button size and location. For TextGen the buttons were below the ND to the left. They were 1.12 cm high x 3.49 cm wide. For

GraphicGen the buttons were to the right of the ND and were 1.27 cm high x 6.03 cm wide. The large different in response time most probably due to the smaller ND and thus smaller information presented on TextGen. Graphic sizes should be evaluated depending on how they will be used, especially if touch screens are utilized.

## **6. Discussion**

This section briefly summarizes the findings of all three experiments. The primary outcome of the experiments was the development of human factors recommendations (See Volume 1). The following sections provide additional information related to the evaluations.

### **6.1. Graphic versus Text Presentations for DataComm**

One of the primary research questions related to DataComm is whether text alone will support pilots or whether alternative displays that include graphics should be included. The research compared text, graphic, and hybrid text and graphic formats and interaction techniques across the three experiments. Overall the findings are that pilots perform better if they are provided graphics when interpreting spatial clearances or messages. (Note this research did not evaluate UMs or instructions that do not affect the route of flight (e.g. transfer of communications, contact/monitor, report requests). This was true both for interpreting a clearance and for checking the request DM messages pilots sent to ATC. Not only did pilots perform better, but also all pilots agreed that to use DataComm they needed to have graphics. This is especially true for complex concatenated clearances with multiple elements.

Due to the need for near to midterm capability, the primary graphic format evaluated was presentation of graphic symbols on a ND. The ND, currently available on the flight deck, already presents pilots with a graphic of their current route. Therefore it is possible to include graphic data on an existing display, or create a new display similar to the ND.

Not all aspects of the designs tested will be available on the flight deck. For example, the GraphicGen capability where pilots use direct manipulation to move a graphic symbol on the display would not be immediately available. However, the techniques are not new with respect to available technology and could be implemented on new aircraft or if aircraft are retrofit.

### **6.2. Clearance Complexity**

Experiment I included number of elements in a clearance to provide a gauge of clearance complexity. As the number of elements in a clearance increased beyond 2 elements, it took longer for pilots to interpret the clearance. The number of errors also increased. The HITL simulation was part-task and the pilots did not need to attend to other tasks, so response times do not reflect times that would be found on a flight deck. However, the data did provide relative time information. It was noted that time to interpret a clearance increased when pilots participated in the dynamic HITL experiments compared to the DC-MAT static simulation. For the dynamic simulation, the aircraft was on autopilot, but pilots were monitoring the flight.

### **6.3. DC-MAT**

The similarity of results among experiments indicate that the static DC-MAT paradigm was useful for a first look at performance with different graphic techniques. The results indicate that graphics being considered for the flight deck can be evaluated using this tool. Air certification personnel or flight deck designers could determine if response times are too long. A more complex simulation is not necessarily needed. Errors are more difficult to determine because pilots always want more information about the scenario and make decisions based on experience. They are sometimes evaluating scenarios based on more information than what is provided;

therefore, they have a tendency to reject clearances. However, this also happened using the dynamic HITL simulator where information is provided about aircraft states.

#### **6.4. Portable DataComm Simulator**

Another contribution of this research was the design of the portable DataComm simulator. The simulator provides a mechanism to continue to evaluate human performance using DataComm including evaluation of the SC-214 message set. The simulator was developed using off-the-shelf components and custom designed software.

#### **6.5. Future Research**

There continues to be a need for future research. Specific considerations are to evaluate the graphic techniques in a full simulation environment under nominal and off-nominal flight conditions. There is a need to evaluate the usefulness of the recommendations, and additional recommendations are likely needed. One area of continued research is graphic display of time information on the flight deck to support not only DataComm but also complex TBOs. Another is the use of touch screens and placement.

## 7. Conclusions

Current DataComm systems use text to provide clearances or messages from ATC to the pilot. The NextGen air space will utilize more complex TBOs that require spatial understanding of aircraft location at any given time. Spatial clearances presented as text can be challenging because of the need to mentally transform the text information into a mental spatial representation. Cardosi et al. (2010) indicated that research addressing presentation methods for DataComm was a high priority for ensuring the successful use of DataComm. Because DataComm is an important enabling technology for NextGen, it is important to develop human factors recommendations to support the evaluation of DataComm interfaces on the flight deck.

This research focused on developing human factors recommendations for providing clearances to the pilot and sending messages from the flight deck to ATC using alternative displays. Three separate exploratory HITL experiments were conducted to evaluate pilot performance and obtain pilot feedback. The first study used a static paradigm called DC-MAT to present clearances from ATC to the flight deck. This study provided significant input to the recommendations and use of graphic formats as well as techniques for concatenating messages in subsequent experiments. The results of the first experiment indicated that a hybrid between graphics and text resulted in better performance than text alone. The results also suggested that instead of separating graphics and text, integrating them onto one graphic display may improve performance. However, the number of data points for the integrated graphic technique was limited; therefore, future research is needed.

Experiments II and III included concatenated clearances to the flight deck as well as evaluating text and graphic techniques for creating pilot requests through DMs sent to ATC. These studies indicated that pilot's performance was enhanced with graphics. All pilots indicated they needed a graphic to support their creation of spatial DM requests to ATC.

The primary objective of this research was the development of human factors recommendations. This objective was met and recommendations are provided in Volume I of the final report. In addition to this primary objective, additional outcomes include development of an evaluation tool for FAA Air Certification Personnel (DC-MAT), and a portable dynamic simulator with ATC station to allow continued research on DataComm messages, presentation formats, and other DataComm considerations.

## 8. Appendix A. ANOVA and Post-Hoc Analyses Tables

### One Element Clearances

ANOVA Summary for One Element Mean Response Time

Source	df	Type III SS	Mean Square	F Value	p-value
<b>RESPONSE</b>	1	416.6642	416.664178	12.55	0.0008*
<b>FORMAT</b>	3	884.7466	294.915536	6.38	0.0009*
<b>FORMAT*RESPONSE</b>	3	392.5077	130.835885	3.94	0.0129*

One Element Comparison of Response Time for FORMAT main Effect

FORMA T	FORMAT	Estimate	Standard Error	df	tValue	Pr> t	Adj	Adj P
<b>TEXT</b>	<b>G+T</b>	1.0296	0.8109	54	1.27	0.2097	Tukey- Kramer	0.586
<b>TEXT</b>	<b>G+T+updUM</b>	-1.5963	0.802	54	-1.99	0.0516	Tukey- Kramer	0.204 3
<b>TEXT</b>	<b>G+T+ASD</b>	-1.7103	0.7232	54	-2.37	0.0217	Tukey- Kramer	0.096 3
<b>G+T</b>	<b>G+T+updUM</b>	-2.6259	0.8528	54	-3.08	0.0033	Tukey- Kramer	.0167 *
<b>G+T</b>	<b>G+T+ASD</b>	-2.7398	0.779	54	-3.52	0.0009	Tukey- Kramer	.0048 *
<b>G+T+up dUM</b>	<b>G+T+ASD</b>	-0.1139	0.7698	54	-0.15	0.8829	Tukey- Kramer	0.998 8

One Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Response Time

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



### 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

#### 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*

#### Two Element Comparison of Response Time for FORMAT Main Effect

FORMAT	FORMA T	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+ updUM	0.8423	0.7798	61	1.08	0.2843	Tukey- Kramer	0.816
TEXT only	G+T+AS D	-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+ updUM	-0.976	0.839	61	-1.16	0.2492	Tukey- Kramer	0.772
G+T	G+T+AS D	-4.191	0.8244	61	-5.08	<.0001	Tukey- Kramer	.0001*
G+T	G+IT+AS	-5.1768	1.0603	61	-4.88	<.0001	Tukey-	.0001*

	<b>D</b>						Kramer	
<b>G+T+ updUM</b>	<b>G+T+AS D</b>	-3.215	0.6544	61	-4.91	<.0001	Tukey- Kramer	.0001*
<b>G+T+ updUM</b>	<b>G+IT+AS D</b>	-4.2008	0.9343	61	-4.5	<.0001	Tukey- Kramer	.0003*
<b>G+T+AS D</b>	<b>G+IT+AS D</b>	-0.9858	0.9211	61	-1.07	0.2888	Tukey- Kramer	0.821

Two Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Response Time

<b>FORMAT*RESPONSE Effect Sliced by FORMAT for RESPONSE_TIME</b>					
<b>FORMAT</b>	<b>DF</b>	<b>Sum of Squares</b>	<b>Mean Square</b>	<b>F Value</b>	<b>Pr &gt; F</b>
<b>TEXT only</b>	1	6.071769	6.071769	0.24	0.726
<b>G+T</b>	1	204.072118	204.072118	2.99	0.0920
<b>G+T+updUM</b>	1	70.713337	70.713337	2.77	0.0960
<b>G+T+ASD</b>	1	1717.03957	1717.039573	67.22	<.0001*
<b>G+IT+ASD</b>	1	445.626894	445.626894	17.45	<.0001*

Two Element ANOVA Summary for Percent Correct

<b>Type 3 Tests of Fixed Effects</b>				
<b>Effect</b>	<b>Num DF</b>	<b>Den DF</b>	<b>F Value</b>	<b>Pr &gt; F</b>
<b>RESPONSE</b>	1	61	4.84	0.0317*
<b>FORMAT</b>	4	61	2.91	0.0286*
<b>FORMAT*RESPONSE</b>	4	61	0.82	0.5153

Two Elements Comparisons of Response Time for FORMAT Main Effect

<b>FORMA T</b>	<b>FORMA T</b>	<b>Estimate</b>	<b>Standard Error</b>	<b>D F</b>	<b>tValue</b>	<b>Pr&gt;  t </b>	<b>Adj</b>	<b>Adj P</b>
<b>TEXT only</b>	<b>G+T</b>	-0.5285	3.7667	61	-0.14	0.8889	Tukey- Kramer	0.9999

<b>TEXT only</b>	<b>G+T+updUM</b>	7.4127	3.0755	61	2.41	0.019	Tukey-Kramer	0.1264
<b>TEXT only</b>	<b>G+T+AS D</b>	4.7991	3.0755	61	1.56	0.1238	Tukey-Kramer	0.5281
<b>TEXT only</b>	<b>G+IT+AS D</b>	-0.7123	3.7667	61	-0.19	0.8506	Tukey-Kramer	0.9997
<b>G+T</b>	<b>G+T+updUM</b>	7.9412	3.3219	61	2.39	0.0199	Tukey-Kramer	0.1318
<b>G+T</b>	<b>G+T+AS D</b>	5.3275	3.3219	61	1.6	0.1139	Tukey-Kramer	0.5008
<b>G+T</b>	<b>G+IT+AS D</b>	-0.1838	3.9704	61	-0.05	0.9632	Tukey-Kramer	1
<b>G+T+updUM</b>	<b>G+T+AS D</b>	-2.6136	2.5111	61	-1.04	0.3021	Tukey-Kramer	0.8354
<b>G+T+updUM</b>	<b>G+IT+AS D</b>	-8.125	3.3219	61	-2.45	0.0173	Tukey-Kramer	0.1171
<b>G+T+AS D</b>	<b>G+IT+AS D</b>	-5.5114	3.3219	61	-1.66	0.1022	Tukey-Kramer	0.4665

## Three Element Clearances

### Three Element ANOVA Summary for Response Time

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

### Three Element Comparison of Response Time for FORMAT Main Effect

FORMA T	FORMA T	Estimate	Standar d Error	DF	tValue	Pr>  t	Adj	Adj P
<b>TEXT only</b>	<b>G+T</b>	3.4551	1.0778	54	3.21	0.0023	Tukey-Kramer	.0118*

<b>TEXT only</b>	<b>G+T+ updUM</b>	2.6249	0.9291	54	2.83	0.0066	Tukey-Kramer	.0325*
<b>TEXT only</b>	<b>G+T+AS D</b>	-0.1779	0.9305	54	-0.19	0.8491	Tukey-Kramer	0.9975
<b>G+T</b>	<b>G+T+ updUM</b>	-0.8302	1.0008	54	-0.83	0.4104	Tukey-Kramer	0.8402
<b>G+T</b>	<b>G+T+AS D</b>	-3.633	1.0021	54	-3.63	0.0006	Tukey-Kramer	.0035*
<b>G+T+ updUM</b>	<b>G+T+AS D</b>	-2.8028	0.8402	54	-3.34	0.0015	Tukey-Kramer	.0082*

### Three Element ANOVA Summary for Percent Correct

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
<b>RESPONSE</b>	1	54	0.73	0.397
<b>FORMAT</b>	3	54	5.36	0.0027*
<b>FORMAT*RESPONSE</b>	3	54	2.78	0.0499*

### Three Element Comparison of Percent Correct for FORMAT Main Effect

FORMA T	FORMAT	Estimate	Standar d Error	DF	tValue	Pr>  t	Adj	Adj P
<b>TEXT only</b>	<b>G+T</b>	3.4551	1.0778	54	3.21	0.0023	Tukey-Kramer	.0118*
<b>TEXT only</b>	<b>G+T+ updUM</b>	2.6249	0.9291	54	2.83	0.0066	Tukey-Kramer	.0325*
<b>TEXT only</b>	<b>G+T+AS D</b>	-0.1779	0.9305	54	-0.19	0.8491	Tukey-Kramer	0.9975
<b>G+T</b>	<b>G+T+ updUM</b>	-0.8302	1.0008	54	-0.83	0.4104	Tukey-Kramer	0.8402
<b>G+T</b>	<b>G+T+AS D</b>	-3.633	1.0021	54	-3.63	0.0006	Tukey-Kramer	.0035*

<b>G+T+ updUM</b>	<b>G+T+AS D</b>	-2.8028	0.8402	54	-3.34	0.0015	Tukey- Kramer	.0082*
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**Three Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Percent Correct**

Effect	FORMAT	DF	Den DF	F Value	Pr > F
<b>FORMAT*RESPONSE</b>	TEXT only	1	54	1.33	0.2536
<b>FORMAT*RESPONSE</b>	G+T	1	54	0.12	0.7318
<b>FORMAT*RESPONSE</b>	G+T+updUM	1	54	1.85	0.1789
<b>FORMAT*RESPONSE</b>	G+T+ASD	1	54	6.01	0.0175*

**Four Element Clearances**

**Four Element ANOVA Summary for Response Time**

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

**Four Element Comparison of Response Time for FORMAT Main Effect**

FORMAT	FORMAT	Estimate	Standard Error	DF	tValue	Pr>  t	Adj	Adj P
<b>TEXT only</b>	<b>G+T</b>	2.7074	1.3765	61	1.97	0.0538	Tukey-Kramer	0.2944
<b>TEXT only</b>	<b>G+T+ updUM</b>	3.6521	1.1201	61	3.26	0.0018	Tukey-Kramer	.0151*
<b>TEXT only</b>	<b>G+T+AS D</b>	0.4435	1.139	61	0.39	0.6984	Tukey-Kramer	0.995
<b>TEXT</b>	<b>G+T+AS</b>	0.9106	1.4844	61	0.61	0.5419	Tukey-	0.9724

<b>only</b>	<b>D</b>						Kramer	
<b>G+T</b>	<b>G+T+ updUM</b>	0.9447	1.2165	61	0.78	0.4404	Tukey- Kramer	0.9364
<b>G+T</b>	<b>G+T+AS D</b>	-2.264	1.234	61	-1.83	0.0714	Tukey- Kramer	0.3636
<b>G+T</b>	<b>G+IT+AS D</b>	-1.797	1.5585	61	-1.15	0.2534	Tukey- Kramer	0.7777
<b>G+T+ updUM</b>	<b>G+T+AS D</b>	-3.209	0.9394	61	-3.42	0.0011	Tukey- Kramer	.0097*
<b>G+T+ updUM</b>	<b>G+IT+AS D</b>	-2.742	1.3374	61	-2.05	0.0447	Tukey- Kramer	0.2553
<b>G+T+ASD</b>	<b>G+IT+AS D</b>	0.4671	1.3533	61	0.35	0.7312	Tukey- Kramer	0.9969

**Four Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Response Time**

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

**Four Element ANOVA Summary for Percent Correct**

<b>Type 3 Tests of Fixed Effects</b>				
<b>Effect</b>	<b>Num DF</b>	<b>Den DF</b>	<b>F Value</b>	<b>Pr &gt; F</b>
<b>RESPONSE</b>	1	61	60.23	<.0001*
<b>FORMAT</b>	4	61	2.51	0.0509
<b>FORMAT*RESPONSE</b>	4	61	0.52	0.7236

## Five Element Clearances

### Five Element ANOVA Summary of Response Time

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

### Five Element Comparison of Response Time for FORMAT Main Effect

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

### 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*

### 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*

### Five Element Comparison for Percent Correct for FORMAT Main Effect

FORMA T	FORMAT	Estimate	Standar d 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+AS D	-2.292	3.5898	61	-0.64	0.5256	Tukey- Kramer	0.9681
TEXT only	G+IT+AS D	-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+AS D	-1.875	3.8774	61	-0.48	0.6304	Tukey- Kramer	0.9886



<b>G+T</b>	<b>G+IT+AS D</b>	-13.54	4.6344	61	-2.92	0.0049	Tukey- Kramer	.0377*
<b>G+T+ updUM</b>	<b>G+T+AS D</b>	7.2917	2.931	61	2.49	0.0156	Tukey- Kramer	0.1069
<b>G+T+ updUM</b>	<b>G+IT+AS D</b>	-4.375	3.8774	61	-1.13	0.2636	Tukey- Kramer	0.791
<b>G+T+AS D</b>	<b>G+IT+AS D</b>	-11.67	3.8774	61	-3.01	0.0038	Tukey- Kramer	.0301*

#### Five Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Percent Correct

<b>Effect</b>	<b>FORMAT</b>	<b>Num DF</b>	<b>Den DF</b>	<b>F Value</b>	<b>Pr &gt; F</b>
<b>FORMAT*RESPONSE</b>	<b>TEXT only</b>	1	61	29.18	<.0001*
<b>FORMAT*RESPONSE</b>	<b>G+T</b>	1	61	6.47	0.0135*
<b>FORMAT*RESPONSE</b>	<b>G+T+updUM</b>	1	61	9.09	0.0037*
<b>FORMAT*RESPONSE</b>	<b>G+T+ASD</b>	1	61	7.37	0.0086*
<b>FORMAT*RESPONSE</b>	<b>G+IT+ASD</b>	1	61	0.1	0.7517

### Six Element Clearances

#### Six Element ANOVA Summary for Response Time

<b>Source</b>	<b>DF</b>	<b>Type III SS</b>	<b>Mean Square</b>	<b>F Value</b>	<b>Pr &gt; F</b>
<b>RESPONSE</b>	1	810.59	810.59	8.11	0.0062*
<b>FORMAT</b>	4	3322.9	830.73	5.43	0.0007*
<b>FORMAT*RESPONSE</b>	4	680	170	1.7	0.1775

### Six Element Comparison of Response Time for FORMAT Main Effect

FORMA T	FORMAT	Estimate	Standar d 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+AS D	-2.786	1.7409	61	-1.6	0.1148	Tukey- Kramer	0.5032
TEXT only	G+IT+AS D	-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+AS D	-5.999	1.9039	61	-3.15	0.0025	Tukey- Kramer	.0205*
G+T	G+IT+AS D	-5.054	2.2875	61	-2.21	0.0309	Tukey- Kramer	0.1902
G+T+ updUM	G+T+AS D	-5.938	1.4276	61	-4.16	0.0001	Tukey- Kramer	.0009*
G+T+ updUM	G+IT+AS D	-4.993	1.9095	61	-2.61	0.0112	Tukey- Kramer	0.0802
G+T+AS D	G+IT+AS D	0.945	1.9095	61	0.49	0.6224	Tukey- Kramer	0.9876

### 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

## Nine Element Clearance

### Nine Element ANOVA Summary for Response Time

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

### Nine Element Comparison of Response time for FORMAT Main Effect

FORMA T	FORMA T	Estimate	Standar d Error	DF	T Value	Pr>  t	Adj	Adj P
<b>TEXT only</b>	<b>G+T</b>	14.844	1.9221	34	7.72	<.0001	Tukey- Kramer	.0001*
<b>TEXT only</b>	<b>G+T+ updUM</b>	10.791	1.5608	34	6.91	<.0001	Tukey- Kramer	.0001*
<b>G+T</b>	<b>G+T+ updUM</b>	-4.053	1.6872	34	-2.4	0.0219	Tukey- Kramer	0.0556

### Nine Element FORMAT\*RESPONSE Interaction Sliced by FORMAT for Percent Correct

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

### Nine Element ANOVA Summary of Percent Correct

Effect	Num DF	Den DF	F Value	Pr > F
<b>RESPONSE</b>	1	35	47.89	<.0001*
<b>FORMAT</b>	2	35	0.13	0.8787
<b>FORMAT*RESPONSE</b>	2	35	1.05	0.3597