2013

The Effectiveness of Pilot Response to Generate Concatenated Downlink Messages after Evaluation of Hybrid Graphic-Text Clearances

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The Effectiveness of Pilot Response to Generate Concatenated Downlink Messages after Evaluation of Hybrid Graphic-Text Clearances

A thesis submitted in partial fulfillment of the Requirements for the degree of Master of Science in Engineering

By

STEVEN BRENT KISS
B.S. The Ohio State University, 2008

2013
Wright State University
I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Steven Brent Kiss ENTITLED The Effectiveness of Pilot Response to Generate Concatenated Downlink Messages after Evaluation of Hybrid Graphic-Text Clearances BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering.

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ABSTRACT

Kiss, Steven Brent, M.S.Egr. Wright State University, 2013. The Effectiveness of Pilot Response to Generate Concatenated Downlink Messages after Evaluation of Hybrid Graphic-Text Clearances.

Data-Link Communication, or DataComm, is a digital text messaging system providing a means of communication between Air Traffic Control (ATC) and pilots. Current Pilot/ATC communication is via voice radio, but the number of ATC operators and voice channels are finite, which limits the number of aircraft voice transmission can accommodate. The number of aircraft within the National Airspace System (NAS) is expected to double between 2004 and 2025, and a transition from voice to DataComm is a necessity. DataComm is an integral part of the NAS and is implemented in incremental phases increasing its functions and capability. There are many advantages with DataComm including providing the ability to send a digital message to a specific plane, the ability to send a long and detailed message with accuracy, as well as providing a platform to add additional features after initial implementation. However, DataComm does have critical integration issues into the current avionic systems and flight deck for commercial airliners. In an attempt to limit the number of DataComm transmissions and to support trajectory based operations, future ATC clearances are expected to increase in length and complexity. Pilots will be required to first understand the clearance, and then decide whether it is acceptable. Clearances that are rejected prompt pilots to create a Downlink Message (DM) to ATC to negotiate clearances. Pilots may also initiate a clearance request with ATC. This research focuses on DM creation after pilot evaluation.
of complex multi-element clearances depicted via text and graphics on a Navigation Display (ND). Two separate touchscreen DM creation interfaces were developed. The research was broken into two separate experiments. All scenarios were presented on a dynamic flight simulator connected to a simulated ATC station.

Experiment I was an exploratory study and recorded response time to interpret a clearance, pilot accuracy, and time to create a DM. A Pilot/ATC communication interface (TextGen) was utilized during Experiment I. TextGen was a menu-based system that allowed pilots to create their own DMs by selecting messages from categories on a touchscreen. Graphics of the DM were presented on a ND in correlation to the original ATC clearance as DMs were constructed. Twenty-Four pilots were tested on ten separate concatenated clearances repeated four times each to comprise a total of forty clearances. Half of the clearance scenarios were designed so that the pilot should reject and half were designed to be acceptable. Verbal comments from Experiment I helped formulate recommendations to improve DataComm interfaces for future implementations within the NAS. The results showed that TextGen was time consuming, required excessive input, and demanded 100% of the pilots’ attention during interaction.

Experiment II had four separate hypotheses and recorded response time to interpret a clearance, pilot accuracy, and times to create a DM. Experiment II tested two separate Pilot/ATC DM creation communication interfaces. One format was TextGen, (tested in Experiment I), and the second was a direct manipulation graphic interface called AutoGen. AutoGen allowed pilots to create DMs by physically touching graphics that were depicted on a ND. The clearance variables within the DM were automatically altered in correlation with the graphic manipulation. Experiment II compared DM
creation time, and response time to interpret a clearance between both presentation formats. Eight separate pilots were tested on both formats.

Results indicated that AutoGen allowed pilots to perform more accurately with less time. The average time to create a DM was significantly less when pilots interacted with AutoGen compared to TextGen. Pilots overwhelmingly preferred the AutoGen interface because of the intuitiveness of the display, ease of use, and automation features. The direct graphic manipulation was preferred over the menu-based system. DM graphics, as well as uplink message (UM) graphics, were preferred to text alone by 100% of the pilots tested.

This research allowed the development of many human factors recommendations. These recommendations could be used by the Federal Aviation Administration (FAA) to develop standards for future Pilot/ATC DataComm interfaces. One recommendation is to ensure that graphics of DMs on the ND are included when pilots create DMs on DataComm interfaces. Another recommendation would be to allow the option for a hybrid version of menu-based system with direct graphic manipulation. The benefits of both formats could be utilized providing the flexibility to generate any DM from the menu-based system and also utilizing the speed and accuracy of the direct manipulation interface.
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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D</td>
<td>Two Dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three Dimensional</td>
</tr>
<tr>
<td>4DT</td>
<td>Four Dimensional Trajectory</td>
</tr>
<tr>
<td>AFRL</td>
<td>Air Force Research Laboratory</td>
</tr>
<tr>
<td>AOC</td>
<td>Air Operator Centers</td>
</tr>
<tr>
<td>ATC</td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>ATM</td>
<td>Air Traffic Management</td>
</tr>
<tr>
<td>ATP</td>
<td>Airline Transport Pilot</td>
</tr>
<tr>
<td>COTS</td>
<td>Commercial Off The Shelf</td>
</tr>
<tr>
<td>CDU</td>
<td>Control Display Unit</td>
</tr>
<tr>
<td>CSD</td>
<td>Cockpit Situation Display</td>
</tr>
<tr>
<td>DataComm</td>
<td>Data Communication</td>
</tr>
<tr>
<td>DM</td>
<td>Downlink Message</td>
</tr>
<tr>
<td>ETA</td>
<td>Estimated Time of Arrival</td>
</tr>
<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
</tr>
<tr>
<td>FMS</td>
<td>Flight Management System</td>
</tr>
<tr>
<td>GA</td>
<td>General Aviation</td>
</tr>
<tr>
<td>HITL</td>
<td>Human In The Loop</td>
</tr>
<tr>
<td>HUD</td>
<td>Heads Up Display</td>
</tr>
<tr>
<td>INI</td>
<td>Initialization</td>
</tr>
<tr>
<td>JPDO</td>
<td>Joint Planning and Development Office</td>
</tr>
<tr>
<td>NAS</td>
<td>National Airspace System</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautical and Space Administration</td>
</tr>
<tr>
<td>ND</td>
<td>Navigation Display</td>
</tr>
<tr>
<td>NextGen</td>
<td>Next Generation Air Transportation System</td>
</tr>
<tr>
<td>RT</td>
<td>Response Time</td>
</tr>
<tr>
<td>RTA</td>
<td>Required Time of Arrival</td>
</tr>
<tr>
<td>SA</td>
<td>Situation Awareness</td>
</tr>
<tr>
<td>TBO</td>
<td>Trajectory Based Operation</td>
</tr>
<tr>
<td>UAS</td>
<td>Unmanned Aerial Systems</td>
</tr>
<tr>
<td>UM</td>
<td>Uplink Message</td>
</tr>
<tr>
<td>VOR</td>
<td>Very High Frequency Omni-Directional Range</td>
</tr>
<tr>
<td>WL</td>
<td>Work Load</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

This research was funded by the FAA NextGen Human Factors Division (ANG-C1), Cooperative Agreement DTFAWA-10-A-80021.

In addition to the research team, Cessna Aircraft Company provided direct support for the completion of this project. Cessna provided access to highly trained pilots as volunteers to serve as research subjects. We also thank them for their support in providing feedback during data collection and the review of the human factors recommendations.

A very special thanks is owed to Tony Merck and Greg Potter for contact support, along with organization and coordination with pilot scheduling at Cessna. Mr. Merck and Mr. Potter were instrumental with their assistance, cooperation, and professionalism.
DEDICATION

I dedicate this thesis to Orville and Wilbur Wright. Without them, Pilot / ATC Data-link Communication would not be necessary.
1.0 Introduction

The year is 2013 and people around the world, especially in the United States, live in a technological age. There are 3D televisions in homes, cars that e-mail when their engine is not running at peak performance, and Unmanned Aerial Systems (UAS) being operated by controllers distantly located from the aircraft. The revolution of smart phones with their computing power has changed how all products are currently developed and applied, especially within flight decks of commercial airliners. Glass cockpits have been utilized within commercial airliners as well other aircraft within General Aviation (GA) and the military for decades. However, communication interfaces still need improvement from a functionality and capability standpoint to meet future need and sustain current safety standards.

The passenger aviation transport industry has had an impeccable safety record, and operations varying from GA to military procedures are all handled with precision. However, this margin of safety needs to be maintained as the system faces the increased air traffic demands predicted for the near future. Data Communications (DataComm) is one key feature of the FAA plan for maintaining this margin of safety and improving the overall efficiency of the National Airspace System (NAS).

The number of planes in the air is expected to double by 2025 (NextGen Concept of Operations, 2007) due to increases in business, package deliveries, and travel in general. Figure 1 shows an increase of flights and passengers transported from 2004 and projected through 2025.
Figure 1. Increase in Flights in the NAS (NextGen Concepts of Operation, 2007)

The current NAS for the United States may not be robust enough to adequately handle this increase in air traffic (NextGen Concept of Operations, 2007). Without improvements to the system, airports will become more congested, and airspace around airport terminals will become more crowded. Delays will be more prevalent, and fuel consumption will increase if planes are required to circle their destination airport until the airport facilities can provide accommodation. If unexpected weather occurs, which is the primary reason for re-routing planes, and the system is already at maximum capacity, serious disruptions could result and have a ripple effect on the whole system.

Because of the projected growth in air traffic, a mandate was signed by President Bush in December 2003 to transform the United States’ current Air Transportation System to meet the needs of 2025. The name given to this project
was Next Generation Air Transportation System (NextGen). The task delegation and high level concepts were developed by the Joint Planning and Development Office (JPDL), and the overall goal was to transition the current airspace system into a structure that can adequately accommodate the increase in flights and passengers while bearing in mind safety, security, and environmental factors. Collaboration, coordination, and communication are essential for success between the Air Traffic Management (ATM), the airport, and all airspace operations. Although there are many levels and factors involved in the entire NextGen concept and operations, air-ground communication is always a key factor. Currently, most communication between pilots and ATC are via voice, and there are many advantages and disadvantages of this system.

2.0 Background

Voice communication between pilot and Air Traffic Control (ATC) has been utilized since the 1930’s, and this system has worked fairly well for airplane separation, as well as expediting planes into and out of airport terminals. There are many advantages and disadvantages of voice communication depicted in Table 1. These findings have been determined from discussions with experienced pilots along with recent research by Nguyen, Bacon, Rorie, Herron, Vu, Strybel, Battiste, (2011); Kraut, Kiken, Billinghurst, Morgan, Strybel, Chiappe, Vu (2011).
Table 1. Advantages and Disadvantages of Voice Communication

<table>
<thead>
<tr>
<th>Voice Communication</th>
<th>Voice Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>Disadvantages</td>
</tr>
<tr>
<td>It is a fast transfer of one or two elements</td>
<td>Pilots often require ATC to repeat clearances due to accent, or language issues</td>
</tr>
<tr>
<td>single clearances</td>
<td></td>
</tr>
<tr>
<td>Pilots are familiar with this current system and do not typically want to change</td>
<td>Message blocking occurs when there are congested radio frequencies</td>
</tr>
<tr>
<td>Pilots can fly with their head up during communication with ATC</td>
<td>Complex concatenated clearances are hard to convey via voice</td>
</tr>
<tr>
<td>Applicable during emergency situations</td>
<td>Not enough ATC operators to utilize voice for future increase in demand within the NAS</td>
</tr>
<tr>
<td>A party line is available for planes to listen on to gain knowledge of weather, and different activities of other planes</td>
<td>Although rare, pilots can sometimes receive and execute another plane’s clearance because of similar call signs</td>
</tr>
</tbody>
</table>

Voice communication cannot meet future NextGen needs as traffic increases. Therefore, a new system needs implemented, and this system in Data Communication.

2.1 Data-Link Communication

Aircraft Data-Link Communication, or DataComm, is defined as a system for sending digital messages back and forth between commercial airline pilots and ground stations including ATC facilities. The information transmitted varies. Examples include data sent to Air Operator Centers (AOC) such as aircraft weight, fuel burn, and engine diagnostics to provide reports on how efficient plane engines are running. DataComm also includes the transmission of clearance or other
information between pilots and ATC. ATC clearances are defined as directions that result in alterations to a plane’s altitude, speed, heading, and/or route of travel.

2.2 Advantages of DataComm

There are many advantages to DataComm over the existing broadcast radio system. DataComm will provide ATC operators the capability to send multiple clearances at once to multiple planes. Read backs of clearances by an ATC operator to ensure accurate interpretation are not needed because DataComm provides a precise and persistent display of the message within the flight deck. The accuracy of each digital message will be precise regardless of the clearance complexity or number of variables (elements) in a clearance or message. Due to the broadcast nature of the simplex radio system, voice transmissions of clearances can be incorrectly accepted by a pilot with a similar call sign to another plane. DataComm’s direct addressing feature sends a digital clearance to a specific plane, preventing such errors.

DataComm provides the opportunity to improve data flow between pilots and ATC while minimizing the potential for errors resulting in overall improved efficiency. This efficiency enhances safety and in turn increases the capacity within the NAS to allow controllers to handle aircraft in a timelier manner, reducing unnecessary excess separation and delays that lead to congestion. As noted by Lee (2011), DataComm is a key enabler to digitally manage 4-D trajectory, potentially resulting in improved flight times and increased throughput.

There are many complexities with the implementation of the technology. The first major domestic U.S. implementation was with the Miami operational trials
in 2002 where DataComm was launched to test its capabilities and potential issues (Mueller, McNally, Rentas, Aweiss, Thipphavong, Gong, Cheng, Walton, Walker, Lee, 2011). Transfer of communication messages as well as limited ATC route clearances were included in the available DataComm messages from ATC, and the system worked. However, after one year of implementation the Federal Aviation Administration (FAA) changed course on system implementation and shelved DataComm until a major revamping of NAS software could be completed. Despite the delay of domestic implementations, DataComm is currently used for oceanic flights because land-based radar is not available to track aircraft (Willems & Hah, 2011). Satellites are used for communication between the pilot and ATC to provide real time data accurately locating the plane, its direction, and speed. However, many planes lack the sophistication necessary within the avionics systems to capitalize on satellites and real time information sharing.

2.3 Aircraft Equipage

There are different levels of sophistication of aircraft equipage. Differences in avionic systems impact what approaches can be implemented in any system upgrade. Two avionic subsystems that are available in commercial aircraft are the Flight Management System (FMS) and the Control Display Unit (CDU). The FMS is the plane’s onboard computer, storing all flight information including the filed flight path, the position of the plane, and all waypoints left in the flight. The CDU is the pilot interface to the FMS and Figure 2 depicts a typical interface. Other variations are closely related to this design and functionality.
There are significant advances in user interfaces in commercial products. Smart phones and tablets are integrated into our daily lives. However, integration of this technology into current avionics is not simple. A sophisticated interface in the cockpit must be integrated into the FMS. Integration requires consideration of safety regulations and significant testing and evaluation. The cost of implementation is also significant. Revamping all aircraft would be extremely expensive. It could be justified if the results were a long term financial or safety benefit.

Fewer changes to the current systems would allow faster implementation, but a redesign may be necessary for mid or long term goals within NextGen.
Increased flights in the NAS would require updating the interface that pilots utilize as a primary tool for data communication with ATC. Increased traffic is expected to result in longer and more complex clearances within the flight deck.

2.4 Complex Clearances

There are many questions and concerns related to implementation of complex route clearances using DataComm. Pilots will have to cognitively understand clearances, decide whether or not to accept them, and then execute in a timely manner. DataComm will use Uplink Messages (UMs) and Downlink Messages (DMs) from the RTCA SC214 message set (RTCA SC-214, 2007). A UM is a single message that ATC sends to the plane, and the number of elements or variables in the UM can vary. An example of a one element UM is UM23 which states: ‘DESCEND TO [LEVEL]’. Level is the one variable, or element, bracketed in this example. To create a clearance for future DataComm systems ATC could send one UM, or concatenate two or more UMs together creating a complex clearance. This would result in multiple directions and elements. One definition of a concatenated clearance could be the number of elements in the clearance. (Gallimore, Shingledecker, Tsang, Ward, Green, Kiss, Munoz, Oh, Crory, Geise, McCullough, 2013)

A DM is a Downlink Message that a pilot can create to initiate a clearance request, or to respond to a clearance proposed by ATC. Pilots could potentially create a DM with multiple segments and elements. The use of complex clearances and complex pilot requests require significant human performance research to investigate their effects on pilot performance. DMs will be an integral part for future NextGen operations, but there are few studies evaluating this aspect of
DataComm. The research conducted for this thesis is focused on DM creation and techniques for efficient communication between pilot and ATC. The use of complex clearances and DM requests is expected within the future due to implementation of Trajectory Based Operations (TBO).

2.5 Trajectory Based Operations

Trajectory based operations is a key enabling concept for the next NAS. Current clearance based operations will transition to TBO. Computer systems will contain all flight plans and aid in conflict resolution (Brandt, Lachter, Dao, Battiste, and Johnson, 2011). There are many definitions and implementations of TBO within the aviation community, but the general idea involves the temporal dimension (or time). Four Dimensional Trajectory, (or 4DT), is a common term referring to this concept including latitude, longitude, altitude, and time. The ‘time’ aspect makes up the fourth dimension and will be applied so that aircraft occupy specific positions at specific times. One reason is to control when planes arrive at airport terminals. Airport arrivals will be more controlled regardless of how busy a terminal is, because it will be possible to track all aircraft and their approach. Each plane’s arrival time will be determined well in advance.

Required Times of Arrival (RTA) will be included in flight plans. RTA’s will alleviate the need for holding patterns above airports, which currently burn an excessive amount of fuel on an annual basis. If airports had a more functional system, then they could better manage the incoming planes into their terminal area. However, adding time pressure will only increase the demands placed on an already stressed system. Therefore, DataComm systems must provide the necessary
functionality to communicate with ATC, including innovative and intuitive interfaces so that RTAs and TBOs can be easily understood. One critical need that must be considered when creating innovative interfaces is Situation Awareness (SA). SA is essential for pilots when making an informed decision. Technological devices for future DataComm will continuously increase in capability, but SA needs to be maintained or exceed the current effectiveness from traditional NDs and other displays within the cockpit.

### 2.6 Situation Awareness

SA was first applied to aviation and it was used to describe the user’s spatial perception of their immediate environment. SA also considers the person’s comprehension of the meaning of their situation along with the projection of their status in the future (Pielot, Krull, Boll, 2010). Pilots must maintain SA at all times during flight, especially during high stress events. It is important to present vital information on flight deck displays as well as redundant information on separate displays such as speed, heading, and altitude. The more a pilot knows about their aircraft, clearance information, and location of other aircraft, the better informed they are when making critical decisions during flight. SA ties back to DataComm because the information displayed is necessary during communication with ATC, including evaluation and negotiation of clearances. The first phase of SA is the ability to perceive the information; therefore, it is imperative that the information displayed to the pilot is easily understood and distinguishable. Too much information on a display could cause excessive clutter that could hinder pilot performance.
2.7 Clutter

Clutter is always a concern when developing new displays and increasing the amount of information that is available to the pilot. “Increasing the amount of information in any type of display introduces the potential for clutter, and balancing what could be provided versus what should be provided, are two completely different questions” (Hah & Schulz, 2011). Another key factor that can alter pilot SA is the phase of flight, whether it ascent, cruise, or descent. “Pilots tend to be more vigilant and aware of both the traffic environment and their aircraft status in the terminal area, making even detection during the arrival and taxi phases more likely than in the cruise and departure phases” (Wickens, Hooey, Gore, Sebok, Koenicke, 2009). Regardless of the attentiveness and vigilance of pilots during different phases of flight, the amount of information to be cognitively processed along with physical input into the control display unit (CDU) will likely increase with future DataComm implementations. However, as computer systems become more advanced, automation will likely play a key role in the future helping to alleviate pilot workload (WL), reduce pilot input error, and decrease response times.

2.9 Problem Defined

Existing operational DataComm interfaces do not possess the necessary functions for pilots to accurately communicate with ATC using the control concepts planned for dealing with future demand under NextGen. The current approach cannot be scaled to meet volume. Figure 3 depicts a CDU, which acts as the pilots' primary interface to the FMS. One problem with this interface is that it has a limited display size. As the NAS transitions clearances from voice to digital, the primary
interface may be required to display the clearances via text. A complex text clearance with multiple elements depicted on the CDU screen would be too congested and confusing for a pilot to decipher. If graphics become the prevalent means to convey the message intent in a more effective manner, this display will be too small to implement all necessary features.

Figure 3. Control Display Unit (CDU)

Excessive pilot input is required using the available equipment and CDU upon acceptance of a voice clearance from ATC and clearances will become more complex for future needs. The current CDU will not fulfill the demands that complex clearances will introduce. In addition, pilots will likely have to create complex DM
messages to ATC for future demand. The current message construction capabilities are simply inadequate.

Time will become a critical factor related to excessive input. 4DT clearances and RTAs will place further stress on the system, and without an effective interface, certain clearances relating to time may become irrelevant if pilots cannot interface with the FMS, or communicate with ATC quickly enough. Small buttons on the CDU also introduce problems especially if the number of button presses increases. The amount of time that pilots take to scan the interface during use could increase with many small buttons, and the potential for incorrect human input may become prevalent.

The standard CDU requires significant manual input and is likely to be ineffective for complex data communication. As the NAS is adapted to temporal data and 4DT clearances, the interfaces that pilots use must also adapt. New navigation displays and communication interfaces will be necessary to present more information to the pilot while maximizing the fluency of the interface. Pilots will be required to have an advanced mental model of the plane’s current position and future trajectory. This reason alone could justify the replacement of the current CDU with an innovative interface to accurately depict spatial information while simultaneously serving as a communication platform.

2.10 Navigation and Mental Maps

Navigation is essential for any task that requires movement over large areas, and maps can effectively convey information to the user. Navigation is often not the primary task, but it is often an important aspect. When operating an aircraft for
example, navigation is vital, especially during communication with ATC. Developing a mental model is critical, because if the information from the map, regardless if paper or digital, cannot translate spatial information, then navigation within an area will be extremely difficult. Once a person’s frame of reference or bearings become distorted, they often rely on wayfinding or a physical map. Wayfinding is a term coined in the 1940’s and Darken and Peterson (2002) describe it as the cognitive element of navigation. The concept does not include any physical movement. Darken and Peterson (2002) defined navigation as the combination of a mental map and wayfinding. Being immersed in an environment from which a person is required to navigate is usually preferred, but if this is not feasible given the task at hand then a physical map may be necessary to gain knowledge of their location and direction. This spatial knowledge can be achieved by studying a map before leaving a location, or during the task itself.

North-up maps and track-up maps each have advantages, but for different tasks. Aretz and Wickens (1992) and Rodes and Gugerty (2012) studied the effects of track up and north up maps and both studies arrived at the same conclusions. Track up displays are better for navigation purposes, and north-up maps provide better SA when planning over long periods of time over large areas.

Regardless of the map type or display features, the key for any map is the transformation of the egocentric perspective to the geocentric perspective (Darken and Peterson, 2002). It is vital for any person utilizing a map to first identify their current position, mentally orient themselves on the map to gauge perspective and bearing, and then locate the position that is desired as the final destination. Darken
and Peterson (2002) found that route following tasks is positively correlated with performance relating spatial memory, spatial visualization, and mental rotation.

An example of a track up map displaying a route following task is displayed on a typical ND for aviation. An example of this display is depicted in Figure 4. The track up display shows the flight plan, or route that is desired in magenta, and includes all waypoints that are along the route to provide spatial awareness.

![Figure 4. ND used in Most Aircraft](image)

The ND in Figure 4 depicts the own ship symbol (the triangle at the bottom of figure 4 depicting the plane’s current location) in the same location on the screen at all times. The range on the display is 500 nautical miles (depicted top left) along with the distance to the next point on the flight plan (top right), which in this example is ZOXBY located 124 nautical miles from the plane’s current position. The
heading at the top and center portion of the ND displays the direction of the aircraft. Very High Frequency Omni-Direction Range (VOR) stations are also depicted to provide landmarks as an aid for spatial awareness.

All aspects of the current ND provide information and SA to pilots. For display of complex clearances, additional information will need to be conveyed in a clear manner, and one way is to use graphics.

2.11 Graphics

Most research has focused on text-based messages to provide clearance information to the flight deck. TBO and complex route clearances using text may increase pilot WL and head down time, while decreasing SA when compared to the current voice system. Graphics depicted on the ND in conjunction with the text could alleviate some of these problems. Lee (2011) stated that graphical representations of 4DT clearances between ATC and the pilot would significantly enhance coordination tasks. Graphic presentations of clearances may be more effective than text clearances alone. The implementation of graphics will be critical for future communication efforts to limit pilot cognitive workload during departure, arrival, or other high stress events. Many aircraft companies are beginning to work on possible designs to graphically enable DataComm. Because clearances and 4DT can be spatially complex, text-based messages may not be the best solution for presentation of information.

Graphics implemented on the ND do not need to be drastic to effectively convey information while simultaneously alleviating pilot confusion and ambiguity. Figures 5 and 6 provide examples of route clearances (Gallimore et al., 2013). In
Figure 5: Text Clearance with Graphics
One specific issue is the exact position of the plane before executing specific sections of the entire clearance. Currently when a pilot receives a voice clearance, the clearance is short and it is understood that it should be executed immediately, unless otherwise stated. For NextGen a clearance could be complex with UMs that require execution at different sections or time during the flight. The clearances may be sequential operations. For this reason, the UMs must be depicted in a clear representation of when and where to begin execution.

Creation of graphics to relay clearance information requires that the graphics are designed to represent the textual meaning. SC-214 DataComm messages are structured similar to voice messages. Research has shown that when graphic ATC clearances are not understood, pilots revert back to the textual clearance (Gallimore
et al., 2013). “A fully capable aircraft data communications link will be able to successfully share real time spatial information, identification, weather, security, and operational status for all aircraft” (NextGen Concept of Operations, 2007).

2.12 Graphic Displays for NextGen

The purpose of this section is to provide examples of graphics that have been researched for the flight deck of commercial airliners for air and ground implementation. Positive and negative features are highlighted, but the overall purpose is to provide examples of how graphics could potentially be implemented to aid pilots in decision making while increasing SA. Two dimensional (2D) displays are currently used on the conventional ND using a top down view (Jedrysik, Moore, Salisbury, Homes, 2009). Some studies have implemented graphics on the conventional 2D display for near-term implementation within NextGen, but others have focused on graphical 3D displays to provide maximum SA, but for far-term implementation.

Although graphics are meant to alleviate ambiguity and increase pilot SA, some graphical implementations are not always beneficial. “Critical to the aggregation of information is portraying it accurately and in a meaningful format” (Jedrysik et al., 2009). Mueller (2007) pointed out that aggregation of information is not enough if it is not portrayed accurately. However, a simple route change depicted with a dashed line can be effective when displayed in correlation with the original flight path as depicted in Figure 7.
Figure 7. New trajectory displayed before accepted by the pilot from Mueller (2007)

All stakeholders involved in the restructuring of the NAS understand how important it is to safely separate planes while taking advantage of the physical airspace and ensuring safety. A Cockpit Situation Display (CSD) developed by the National Aeronautical and Space Administration (NASA) attempt to accomplish this, and an example of the CSD is depicted in Figure 8.

Figure 8a. NASA CSD from Johnson, Ho, Battiste, Vu, Lachter, Ligda, Dao, Martin (2010). 8b. CSD Spacing Status and Command Displays
The CSD depicts a 3D world with the plane’s current position at the center in Figure 9a and Figure 9b. The air traffic around the own ship aircraft is presented along with their direction and any potential collision course. The CSD uses a top down and perspective view.

![Figure 9a. NASA CSD Top down view alerting traffic conflict](image1)

Figure 9a. NASA CSD Top down view alerting traffic conflict

![Figure 9b. 3D display with vertical resolution to conflict](image2)

Figure 9b. 3D display with vertical resolution to conflict (Battiste, Johnson, Johnson, Granada, Dao, 2007)

![Figure 10a. 3D weather display mode proximity alert mode CSD](image3)

Figure 10a. 3D weather display mode proximity alert mode CSD (Battiste et al., 2007)

![Figure 10b. 3D NASA CSD Ground](image4)

Figure 10b. 3D NASA CSD Ground

Figure 10a and 10b are still depicted in a 3D world, but are used to avoid unexpected weather cells and terrain. However, 3D perspective displays do not
necessarily improve perception and performance. “2D displays can actually depict the pitch and roll of an aircraft, not just its yaw, while still maintaining the traditional map layering and scale invariance common to 2D representations” (Jedrysik et al., 2009). 2D displays support certain visual representations that are not feasible in 3D displays. Implementation of complex 3D perspective display is not feasible for near-term or mid-term NextGen.

NASA has investigated graphics presented on the Heads-Up-Display (HUD) and surface map display for support of pilot ground operations. These displays depict what the pilot must accomplish in real time and the final destination location depicted in Figure 11.

![Figure 11. NASA simulator with 4DT HUD and surface map display.](image)

Figure 11. NASA simulator with 4DT HUD and surface map display. Hooey, Foyle, Andre (2002).
Another NASA concept explains what features might be necessary when implementing 4DT clearances onto the HUD for ground operations. Pilots will be able to view their speed, current taxiway assignment, and future taxiways all through a digital format without dropping their head to view an instrument panel (Cheng, Andre, Foyle, 2009). Figure 12 depicts all the information digitally presented on the HUD for RTAs and Estimated Time of Arrival (ETA) requirements.

![Figure 12. HUD for 4DT surface operations in manual mode from Cheng, Andre, Foyle (2009).](image)

(Shelton, Prinzel, Jones, Allamandola, Arthur III, Bailey, 2009) performed a study testing 4DT operations with DataComm clearances and traffic on a graphical surface map display shown in Figure 13. Results from the study indicate that in conjunction with verbal read backs, SA significantly increased. Graphical depictions of RTA and 4DT clearances improve the capability of the pilots within the flight deck. Safety is always the number one concern and is the driving factor for further
research. Newer technologies will need to be implemented for future demand to sustain current safety standards.

Figure 13. NASA surface map display (Shelton et al., 2009)

(Van Marwijk, Mulder, Mulder, van Paassen, and Borst, 2009) and (Mulder, Winterberg, van Paassen, 2010) have been investigating an interface for in-flight 4DT navigation planning. Figure 14 illustrates a 4DT concept depicted on a ND using ellipses to indicate the precise position the aircraft needs to occupy in order to satisfy future RTA demands. The purpose of this display is to provide a 3D position along with a time to arrive at that position. Research indicated that the added ellipses on the traditional ND and vertical altitude situation display did not provide any significant advantage with respect to pilot performance.
In summary, current research investigating graphic display formats for NextGen illustrates the complexity of future operations and that graphic presentations will be needed to support pilot operations. (Hooey et al., 2002; Shelton et al., 2009; Van Marwijk et al., 2009; Johnson et al., 2010)

2.13 Menu-Based and Direct Manipulation Interfaces

Menu-based systems and direct manipulation interfaces both have advantages and disadvantages. Several studies will highlight benefits of both and relate how the results are applicable when designing future DataComm interfaces for NextGen implementation.
The concept of a direct manipulation interface is the design of controls and displays that mimic characteristics of the natural environment, which is also directly related to how users think about a physical process (Preece, Rogers, Sharp, Benyon, Holland, Carey, 1994). A study conducted in 1993 compared a direct manipulation interface versus a menu-based interface on an e-mail system (Benbasat, Todd, 1993). The results showed that the direct manipulation allowed subjects to complete the given task quicker than with the menu-based system. However, after repeated testing on the same subjects over several days, results showed that the time difference was not significant. Participants’ learning curve became a factor, and the time benefits of the direct manipulation were no longer present. In terms of accuracy, there was no significant difference between menu-based and direct manipulation interfaces. Karrer, Wittenhagen, and Borchers, (2009) studied direct manipulation video navigation on mobile touchscreen devices. The direct manipulation features were preferred by subjects because of the intuitiveness of the display, the ease of use, and precision. Reisman, Davidson, and Han (2009) presented a screen-space method which allowed direct control in 2D and 3D on a multi-touch surface for terrain and object rotation and manipulation. The research concluded that some users had difficulty with the complexity of the 3D direct manipulation interface, but also that the problems are imitable. All studies discussed in this section have demonstrated that direct manipulation interfaces can be effective for use for many applications.

Menu-based systems may be easier to integrate into existing aircraft systems because not all aircraft have graphic capability on existing displays. A menu-based
system is text-based and does not require multi-touch capacitive touchscreens or advanced training procedures. However, direct manipulation could potentially be more beneficial in terms of pilot performance, (both accuracy and response time), and worth the financial investment to implement for midterm technologies within NextGen versus waiting for far-term implementation. This thesis evaluates pilot performance when utilizing a menu-based touchscreen versus a direct graphic manipulation interface for creating Downlink Messages (DMs).

3.0 Research Objectives

One objective of this research was to investigate techniques that support pilot creation of DMs to ATC with interface formats that include graphic representations. Gallimore et al., (2013) investigated pilot performance during interpretation of clearances (composed of SC-214 uplink messages) using hybrid graphics and text clearances. The results indicated that graphics are essential for understanding complex clearances from ATC.

In this study, pilots received DataComm clearances from ATC and responded using DMs if the clearance was considered unacceptable or required negotiation. DM creation included requests for alternative routes, altitudes, speeds, and temporal data. An accurate depiction of a complex route change is likely to require graphic presentations to facilitate the composition of the request and permit error checking before transmission. This research focused on presentation and interaction formats to allow pilots to send DM requests to ATC. The inclusion of responding to a clearance from ATC during flight allowed pilots to obtain SA that
might not have been possible if they only created DMs without simulating the entire process.

A second objective was to support the development of human factors recommendations relating pilot creation of DM requests to ATC for route changes. The recommendations provide an opportunity for the development of standards to support the evaluation of graphic displays for DataComm.

### 3.2 Human-In-The-Loop Experiments

This research was conducted using two Human-In-The-Loop (HITL) experiments. Experiment I was an exploratory study to evaluate an interface that used text-based methods for creating DMs (TextGen). This first study was used primarily to obtain pilot suggestions for the design of the interface rather than to test specific hypotheses. Experiment II was designed to evaluate pilot performance using two different DM creation interfaces, menu-based (TextGen), and direct manipulation-based (AutoGen). Each experiment, including results and discussion, is discussed separately.
4.0 Experiment I – TextGen: A Menu-Based DM Creation Interface

4.1 Method

4.1.1 Experimental Design

This exploratory study was conducted to obtain pilot feedback as well as baseline data of response times and errors using a text-based DM creation interface. The primary objective was to obtain feedback that could be used to support the creation of human factors recommendations and other presentation methods. No independent variables were manipulated. A HITL simulation was utilized to obtain pilot feedback.

The human performance data 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 correctly rejected)
4) Pilot Accuracy (Correct Accepts and Correct Rejects) as a function of the # of elements in a clearance
5) Pilot Opinions

4.1.2 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 were 10,125.
4.1.3 Apparatus

4.1.3.1 Hardware

An overview diagram of the hardware and software for the simulator is presented in Figure 15. Each component is briefly described followed by a description of the DataComm interface software created for simulation.

![Diagram of the Portable DataComm HITL Simulator.](image)

**Figure 15. Diagram of the Portable DataComm HITL Simulator.**

4.1.3.1.1 Computers

The two computers (Comp1, Comp2) were 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 a simulated ATC operator station.

### 4.1.3.1.2 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.
4.1.3.1.3 Projector and Screen

The Projector was an Epson (Model G5450WUNL) 1920 x 1200 LCD with an optional short throw lens. The projection screen was a DaLite screen (84” x 52”) which supports wide projection angles. Figures 16 through 18 are photographs of the simulator, cockpit, and projector.

Figure 16. Two Computers Next to the Simulator
Figure 17. Two LCD Touch Screen Displays Inside the Cockpit. Yoke, Throttles and Flaps are also Visible

Figure 18. DaLite Projection Screen and Epson Projector
4.1.3.2 Software

The simulator was built using JAVA 7.7 in the Netbeans IDE environment (Version 7.1.1). Netbeans was a platform framework for JAVA which stored, compiled, and ran all code once finalized.

4.1.3.2.1 X-Plane 10

X-Plane 10 is Commercial-Off-The-Shelf (COTS) 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.

4.1.3.2.2 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.

4.1.3.2.3 ATC Station

ATC Station was developed to simulate sending clearances to the DataComm interface software under evaluation, and to receive the DMs sent by the pilot. The program included the following capabilities:

1) Ran pre-constructed scenario files to initiate flight plans, set X-Plane variables within X-plane software and in the DataComm Interface Software, and sent pre-set clearances automatically to the pilot.

2) Allowed a user to create a clearance real-time during the simulation to communicate with the pilot if needed.

3) Send and receive all messages through the DataComm Interface Software.
4) Display and record all messages sent and received from the simulator either in split or mixed mode (All messages are also time stamped)

The ATC Station is the main driver that controls the simulator. All scenarios and flight plans are stored on this system. The four capabilities described above are depicted in Figure 19.

![Figure 19. ATC Screenshot Depicting Ability to Create Clearances](image)

4.1.3.2.4 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 flight plan was exported and transferred to the simulator housing X-plane for input to the FMS.

4.1.4 Stimuli

4.1.4.1 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 2 lists the ten clearances. There were a total of twenty flight paths used to present the 40 clearances within 20 flight scenarios. The 20 separate flight scenarios were authentic flight plans and the ND provided information about airports, VOR (Very high frequency Omni-directional Range) stations, NDB (Non-Directional Beacons), and Waypoints.
### Table 2. Ten Clearances Used for Experiment I

<table>
<thead>
<tr>
<th>UM Numbers</th>
<th>Clearance Text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Three Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM64, UM68</td>
<td>OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td><strong>Four Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM65, UM68</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td>UM188, UM97</td>
<td>AFTER PASSING [position] MAINTAIN [speed]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM46, UM310</td>
<td>CROSS [position] AT LEVEL [level]. AT LEVEL [level single] MAINTAIN [speed]</td>
</tr>
<tr>
<td><strong>Five Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM23, UM77, UM97</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM76, UM339</td>
<td>AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td>UM20, UM77, UM97</td>
<td>CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM27, UM339</td>
<td>CLIMB TO REACH [level] BEFORE PASSING [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td><strong>Six Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM25, UM78, UM97</td>
<td>AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM28, UM76, UM97</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
</tbody>
</table>

### 4.1.4.2 Scenario Files

There were three main input files that were required for the execution of each scenario. These three files were a flight plan, an Initialization (INI) File, and a Script File. Each scenario began with an authentic flight within the United States and utilized a Boeing 777 (for fuel burn and weight to accurately estimate time in...
between waypoints). Once created, all flight plans were exported as a file and transferred to the ATC computer. An example of a flight plan is provided in Figure 20 below.

![Figure 20. Screenshot of Example Flight Plan](image)

All waypoints filed in the FMS starting and ending with an airport identifier

The INI file provided all the pre-defined parameters needed for the simulated flight to begin. The parameters included the starting latitude and longitude of the plane, the starting altitude, airspeed, heading, and the Zulu time for the specific scenario. The INI file also included the zoom level of the ND on both touchscreens, the autopilot state (on or off), whether or not to draw the DM graphic on the DM interface, as well as which flight plan and script file to initiate.
An example of an INI file is summarized and provided in Figure 21.

Data predetermined for each scenario to start the plane off at a specific latitude, longitude, altitude, heading, airspeed, autopilot, FMS Page, Zoom level, Current Zulu Time, Downlink Message Graphics On/Off

```
stimulus_filename: scenario_1_script.txt
fms_plan: Seattle_to_Boise_.fms
lat: 47.252
lon: -122.309
alt: 12000
heading: 143
as: 480
source: gps
ap: on
ap_type:iloc, v/s
fms_page: 3
zoom: 160
time: 13:00:00
drawdm: 1
```

Figure 21. Screenshot of Example INI File

The third file to successfully build a scenario was the script file. This file contained the clearance information sent from the simulated ATC station and displayed on the DM creation communication interface. The file included the delay in seconds from either the beginning of each scenario or the previous clearance once answered, the Uplink Message (UM #) from the SC-214 Message Set, the variables contained within each UM, and the reason for the clearance (which was depicted above the text clearance on the communication interface). An example of a script file is depicted in Figure 22. For this specific scenario there are three separate concatenated clearances.

```
#  
[0:03] [um 27 410, SUMMA um 339 SUMMA, 10083, YKM] [0] [WEATHER]
[0:03] [um 20 410 um 77 SUMMA, BTG um 97 BTG, 150] [0] [TRAFFIC]
[0:03] [um 76 1807.10, SELAH um 339 SELAH, 10083, MARRK] [0] [MILITARY]
```

Figure 22. Screenshot of Example Script File
4.1.5 DataComm Interface: TextGen

Figure 23 illustrates the TextGen interface that provided pilots with an additional ND that emulated the primary ND, and was depicted on the upper left window of the screen. The ND display provided the current flight path in correlation with the ATC clearance via graphics. The ATC clearance was also presented as text in the second window on the right which is the same format used by Gallimore et al. (2013). Beneath the ND was a window that included a WILCO and UNABLE button. When a clearance was received from the simulated ATC station, the pilot reviewed the clearance, and selected WILCO or UNABLE.

Figure 23. Screen Shot of TextGen with ND and Clearance. (Note only VOR stations are currently selected as overlay so the waypoint reference in the clearance is not visible.)
If WILCO was selected, the screen cleared and the flight continued. If the pilot chose UNABLE, the bottom portion of the screen changed and provided the capability to request an alternate clearance using DMs (Figure 24).

**Figure 24. TextGen Interface (Phase after Rejecting the Clearance)**

Text categories for DM messages were listed. The pilot selected a category and the information expanded on the screen to list the possible DM messages (Figure 25). 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 (Figure 25), but changed to green after the waypoint was added by the pilot. The text message was written on the window above the category window. 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 orange graphics. The pilot followed this sequence to concatenate 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 the time to accept a clearance and the time to reject a clearance and create the DM. The system also recorded the DM message created.
Figure 25. Screen Shot of TextGen with Categories for Selecting DMs. (The Pilot has Accepted the Three DMs Listed Under the ND.)

Figure 26 depicts a de-cluttered ND, (i.e. VOR stations, waypoints, or Non-Directional Beacons (NDBs) are not presented), with the original graphic flight plan path as a magenta line. All sections of the display that are labeled are dynamically changing variables during the HITL simulation. During practice trials pilots were instructed to reference these variables when reviewing a clearance to support their decision of whether or not to accept the clearance.
Figure 26. A de-cluttered ND highlighting the dynamic variables

4.1.5.1 Procedures

The HITL flight simulator and ATC station were portable and placed in a hanger at Cessna in Wichita, Kansas for eleven days. Volunteer pilots were provided with an informed consent and participant instructions and were then trained with four practice trials (8 clearances) to become familiar with the interface and rules for
accepting (WILCO) or rejecting (UNABLE) based on the scenarios. The basic rules for rejecting or accepting a clearance are listed in Table 3.

Table 3. Rules for Unable and WILCO

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

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 with a series of questions Appendix D, asked to give their opinions about the interface, and thanked for their participation.
4.2 Experiment I 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. Although the primary interest is in DM creation time rather than times for responding to clearances which was evaluated in the Gallimore et al. (2013) study, response time and percent correct were also evaluated so that readers can compare results from this dynamic simulation study using similar interfaces to that of Gallimore et al., which used static displays. Similarity or differences in the results for clearance understanding and times support comparisons between the different simulation methods. It is possible that dynamic simulation results in reduced response times when compared to static simulation.

4.2.1 Mean Response Time

4.2.1.1 Response Time for Correct Accepts and Correct Rejections

Figure 27 presents the mean response time for correctly accepting and rejecting a clearance. Both times were very similar. The variability in response times was high for correct both response types. Summary statistics are presented in Table 4.
Figure 27. Mean Response Time for Correct Accepts and Correct Rejections

Table 4. Summary Statistics for Mean Response Time for Correct Accepts and Correct Rejections

<table>
<thead>
<tr>
<th>Level</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correctly Accepted</td>
<td>304</td>
<td>24.02</td>
<td>19.43</td>
<td>1.11</td>
<td>21.83</td>
<td>26.22</td>
<td>3.85</td>
<td>103.11</td>
</tr>
<tr>
<td>Correctly Rejected</td>
<td>345</td>
<td>25.13</td>
<td>27.38</td>
<td>1.47</td>
<td>22.23</td>
<td>28.03</td>
<td>2.59</td>
<td>157.65</td>
</tr>
</tbody>
</table>

4.2.1.2 Response Time to Interpret Clearances

The response time to interpret each clearance (time to WILCO or UNABLE) was recorded. Table 5 provides summary statistics for the ten clearances. The table includes the mean, standard deviation, standard error mean, upper and lower 95% confidence intervals, and the number of samples for each clearance. The text for
each clearance is provided in Table 6. Figure 28 displays a bar graph of each clearance showing the Mean Response Time to interpret each clearance.
Table 5. Summary Statistics for RT to Interpret Clearance separated by clearance and UMs

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err Mean</th>
<th>Upper 95% Mean</th>
<th>Lower 95% Mean</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UM27, UM339</strong></td>
<td>36.15</td>
<td>33.41</td>
<td>3.54</td>
<td>43.2</td>
<td>29.12</td>
<td>89</td>
</tr>
<tr>
<td><strong>UM64, UM68</strong></td>
<td>19.74</td>
<td>19.62</td>
<td>2.02</td>
<td>23.75</td>
<td>15.72</td>
<td>94</td>
</tr>
<tr>
<td><strong>UM20, UM77, UM97</strong></td>
<td>19.39</td>
<td>14.08</td>
<td>1.46</td>
<td>22.29</td>
<td>16.48</td>
<td>92</td>
</tr>
<tr>
<td><strong>UM28, UM76, UM97</strong></td>
<td>27.29</td>
<td>29.58</td>
<td>3.05</td>
<td>33.36</td>
<td>21.24</td>
<td>94</td>
</tr>
<tr>
<td><strong>UM25, UM78, UM97</strong></td>
<td>31.56</td>
<td>30.76</td>
<td>3.17</td>
<td>37.87</td>
<td>25.27</td>
<td>94</td>
</tr>
<tr>
<td><strong>UM65, UM68</strong></td>
<td>17.17</td>
<td>14.01</td>
<td>1.45</td>
<td>20.06</td>
<td>14.28</td>
<td>93</td>
</tr>
<tr>
<td><strong>UM23, UM77, UM97</strong></td>
<td>19.47</td>
<td>21.49</td>
<td>2.22</td>
<td>23.9</td>
<td>15.05</td>
<td>93</td>
</tr>
<tr>
<td><strong>UM188, UM97</strong></td>
<td>29.06</td>
<td>32.92</td>
<td>3.41</td>
<td>35.84</td>
<td>22.28</td>
<td>93</td>
</tr>
<tr>
<td><strong>UM76, UM339</strong></td>
<td>25.66</td>
<td>24.91</td>
<td>2.56</td>
<td>30.73</td>
<td>20.59</td>
<td>95</td>
</tr>
<tr>
<td><strong>UM46, UM310</strong></td>
<td>22.35</td>
<td>23.8</td>
<td>2.54</td>
<td>27.39</td>
<td>17.31</td>
<td>88</td>
</tr>
</tbody>
</table>
Table 6. Ten clearances and the Individual UMs for each Clearance, Separated by # of Elements in a Clearance

<table>
<thead>
<tr>
<th>UM Numbers</th>
<th>Clearance Text</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Three Element Clearance</strong></td>
<td></td>
</tr>
<tr>
<td>UM64, UM68</td>
<td>OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td><strong>Four Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM65, UM68</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td>UM188, UM97</td>
<td>AFTER PASSING [position] MAINTAIN [speed]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM46, UM310</td>
<td>CROSS [position] AT LEVEL [level]. AT LEVEL [level single] MAINTAIN [speed]</td>
</tr>
<tr>
<td><strong>Five Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM23, UM77, UM97</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM76, UM339</td>
<td>AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td>UM20, UM77, UM97</td>
<td>CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM27, UM339</td>
<td>CLIMB TO REACH [level] BEFORE PASSING [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td><strong>Six Element Clearances</strong></td>
<td></td>
</tr>
<tr>
<td>UM25, UM78, UM97</td>
<td>AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>UM28, UM76, UM97</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
</tbody>
</table>
Figure 28. RT to Interpret Clearance separated by clearance and UMs
4.2.1.3 Response Time to Interpret Clearance

The response time to interpret each clearance as a function of the number of elements was recorded. Table 7 provides summary statistics for three, four, five, and six element clearances. The table includes the mean, standard deviation, standard error mean, upper and lower 95% confidence intervals, and the number of samples for each clearance. Figure 29 displays a bar graph of the data.

Table 7. Summary Statistics for RT to Interpret Clearance by Number of Elements

<table>
<thead>
<tr>
<th></th>
<th>3 Element Clearances</th>
<th>4 Element Clearances</th>
<th>5 Element Clearances</th>
<th>6 Element Clearances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>17.58</td>
<td>19.43</td>
<td>21.99</td>
<td>24.63</td>
</tr>
<tr>
<td>Std Dev</td>
<td>13.18</td>
<td>15.17</td>
<td>17.48</td>
<td>18.97</td>
</tr>
<tr>
<td>Std Err Mean</td>
<td>1.37</td>
<td>0.93</td>
<td>0.92</td>
<td>27.41</td>
</tr>
<tr>
<td>Upper 95% Mean</td>
<td>20.32</td>
<td>21.26</td>
<td>23.8</td>
<td>27.41</td>
</tr>
<tr>
<td>Lower 95% Mean</td>
<td>14.86</td>
<td>17.59</td>
<td>20.18</td>
<td>21.84</td>
</tr>
<tr>
<td>N</td>
<td>92</td>
<td>266</td>
<td>359</td>
<td>181</td>
</tr>
</tbody>
</table>
4.2.1.4 Mean Time to Create a DM

Table 8 provides summary statistics for RT to create a DM using TextGen. There were three outliers that had excessive 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>
<thead>
<tr>
<th>Number Data Pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>337</td>
<td>81.89</td>
<td>40.12</td>
<td>2.19</td>
<td>77.59</td>
<td>86.18</td>
<td>4.88</td>
<td>207.67</td>
</tr>
</tbody>
</table>
4.2.2 Mean Percent Correct

Figure 30 presents the mean percent correct accepts and mean percent correct rejections. Pilots correctly reject clearances with more accuracy than accepting them. The standard deviation is large (46.81\%). Table 9 summarizes the statistics for these data.

![Figure 30. Pilot Mean Percent Correct for Correct Accepts and Correct Rejections](image-url)
<table>
<thead>
<tr>
<th>Correct Answer</th>
<th>Pilot Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accept</td>
</tr>
<tr>
<td>Accept</td>
<td>67.71 %</td>
</tr>
<tr>
<td></td>
<td>Std Dev 46.81</td>
</tr>
<tr>
<td></td>
<td>Std Error 02.14</td>
</tr>
<tr>
<td></td>
<td>CI: 63.51 and 71.91</td>
</tr>
<tr>
<td></td>
<td>N = 480</td>
</tr>
<tr>
<td>Reject</td>
<td>23.33 %</td>
</tr>
<tr>
<td></td>
<td>Std Dev = 42.34</td>
</tr>
<tr>
<td></td>
<td>Std Error = 01.93</td>
</tr>
<tr>
<td></td>
<td>CI: 72.87 and 80.46</td>
</tr>
<tr>
<td></td>
<td>N = 480</td>
</tr>
</tbody>
</table>
4.2.2.1 Mean Percent Correct by Clearance

The accuracy of all pilots for each clearance was averaged and is presented in table 10. The percentages combined all correct accepts and correct rejections as a single average. Figure 31 displays the accuracy (percentage correct) separated by clearance and UMs as a bar graph.

Table 10. Pilot Accuracy (Percentage Correct) separated by Clearance

<table>
<thead>
<tr>
<th>Clearance (UMs)</th>
<th>Accuracy (% Correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UM27, UM339</td>
<td>80.85%</td>
</tr>
<tr>
<td>UM46, UM310</td>
<td>75.00%</td>
</tr>
<tr>
<td>UM20, UM77, UM97</td>
<td>92.71%</td>
</tr>
<tr>
<td>UM25, UM78, UM97</td>
<td>95.79%</td>
</tr>
<tr>
<td>UM23, UM77, UM97</td>
<td>69.79%</td>
</tr>
<tr>
<td>UM76, UM339</td>
<td>26.32%</td>
</tr>
<tr>
<td>UM64, UM68</td>
<td>50.53%</td>
</tr>
<tr>
<td>UM28, UM76, UM97</td>
<td>67.71%</td>
</tr>
<tr>
<td>UM65, UM68</td>
<td>80.21%</td>
</tr>
<tr>
<td>UM188, UM97</td>
<td>84.38%</td>
</tr>
</tbody>
</table>
Figure 31. Accuracy (Percentage Correct) Separated by Clearance and UM

4.2.2.2 Mean Percent Correct by Number of Elements

The accuracy of all pilots was averaged and presented in table 11. The data were separated by number of elements for each clearance. The percentages combined all correct accepts and correct rejections as a single average. Figure 32 displays the accuracy (percentage correct) separated by number of elements as a bar graph.
### Table 11. Pilot Accuracy (Percentage Correct) separated by Number of Elements

<table>
<thead>
<tr>
<th>Clearance (# of Elements)</th>
<th>Accuracy (% Correct)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Element Clearances</td>
<td>50.53%</td>
</tr>
<tr>
<td>4 Element Clearances</td>
<td>79.86%</td>
</tr>
<tr>
<td>5 Element Clearances</td>
<td>67.42%</td>
</tr>
<tr>
<td>6 Element Clearances</td>
<td>81.75%</td>
</tr>
</tbody>
</table>

### Figure 32. Pilot Accuracy (Percentage Correct) separated by Number of Elements

#### 4.2.3 Response Time and Accuracy of Clearance and Pilot Age

The response times and accuracy of clearance interpretation were recorded as a function of pilot age. Table 12 displays the summary information of the average RT to interpret a clearance and accuracy for each pilot. The RT to interpret the
clearances as a function of age is plotted in Figure 33. Pilot accuracy as a function of age is plotted in Figure 34.

Table 12. Twenty-Four Subjects Ordered by Age Displaying Accuracy (% Correct) and RESPONSE TIME to Interpret Clearances for Experiment I.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>% Correct</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 24</td>
<td>29</td>
<td>80</td>
<td>14.7</td>
</tr>
<tr>
<td>Subject 10</td>
<td>33</td>
<td>75</td>
<td>24.62</td>
</tr>
<tr>
<td>Subject 22</td>
<td>33</td>
<td>72.5</td>
<td>11.82</td>
</tr>
<tr>
<td>Subject 20</td>
<td>36</td>
<td>75</td>
<td>21.9</td>
</tr>
<tr>
<td>Subject 13</td>
<td>37</td>
<td>70</td>
<td>30.9</td>
</tr>
<tr>
<td>Subject 9</td>
<td>41</td>
<td>75</td>
<td>17.42</td>
</tr>
<tr>
<td>Subject 23</td>
<td>41</td>
<td>77.5</td>
<td>16.31</td>
</tr>
<tr>
<td>Subject 14</td>
<td>42</td>
<td>75</td>
<td>15.05</td>
</tr>
<tr>
<td>Subject 11</td>
<td>44</td>
<td>75</td>
<td>25.45</td>
</tr>
<tr>
<td>Subject 16</td>
<td>44</td>
<td>70</td>
<td>20.92</td>
</tr>
<tr>
<td>Subject 5</td>
<td>45</td>
<td>72.5</td>
<td>40.24</td>
</tr>
<tr>
<td>Subject 3</td>
<td>46</td>
<td>70</td>
<td>19.18</td>
</tr>
<tr>
<td>Subject 7</td>
<td>47</td>
<td>75</td>
<td>20.56</td>
</tr>
<tr>
<td>Subject 12</td>
<td>48</td>
<td>72.5</td>
<td>23.42</td>
</tr>
<tr>
<td>Subject 4</td>
<td>49</td>
<td>80</td>
<td>34.77</td>
</tr>
<tr>
<td>Subject 2</td>
<td>52</td>
<td>67.5</td>
<td>29.27</td>
</tr>
<tr>
<td>Subject 17</td>
<td>53</td>
<td>76.3</td>
<td>23.98</td>
</tr>
<tr>
<td>Subject 15</td>
<td>55</td>
<td>67.5</td>
<td>24.88</td>
</tr>
<tr>
<td>Subject 19</td>
<td>55</td>
<td>67.5</td>
<td>36.2</td>
</tr>
<tr>
<td>Subject 18</td>
<td>56</td>
<td>70</td>
<td>28.93</td>
</tr>
<tr>
<td>Subject 1</td>
<td>57</td>
<td>70</td>
<td>22.48</td>
</tr>
<tr>
<td>Subject 8</td>
<td>57</td>
<td>55</td>
<td>23.73</td>
</tr>
<tr>
<td>Subject 6</td>
<td>59</td>
<td>75</td>
<td>29.74</td>
</tr>
<tr>
<td>Subject 21</td>
<td>64</td>
<td>72.5</td>
<td>27.26</td>
</tr>
</tbody>
</table>
Figure 33. RT to Interpret Clearances as a Function of Age

Figure 34. Pilot Accuracy as a Function of Age
4.2.3.1 Response Time and Accuracy of Clearance and Pilot Experience

The response times and accuracy of clearance interpretation were recorded as a function of pilot experience measured in flight hours. Table 13 displays the summary information for all twenty-four pilots displaying the mean response time to interpret a clearance and accuracy for each pilot. Accuracy as a function of pilot experience is plotted in Figure 35. The RT to interpret the clearances as a function of pilot experience is plotted in Figure 36.

Table 13. Twenty-Four Subjects Ordered by Flight Hours Experience Displaying Accuracy (% Correct) and RESPONSE TIME to Interpret Clearances for Experiment I

<table>
<thead>
<tr>
<th>Subject</th>
<th>Experience (Hours)</th>
<th>% Correct</th>
<th>RT</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>1500</td>
<td>70</td>
<td>30.9</td>
</tr>
<tr>
<td>20</td>
<td>3000</td>
<td>75</td>
<td>21.9</td>
</tr>
<tr>
<td>10</td>
<td>4000</td>
<td>75</td>
<td>24.62</td>
</tr>
<tr>
<td>22</td>
<td>4000</td>
<td>72.5</td>
<td>11.82</td>
</tr>
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<td>4000</td>
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<td>34.77</td>
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<td>5000</td>
<td>80</td>
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<td>6000</td>
<td>77.5</td>
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</tr>
<tr>
<td>2</td>
<td>8000</td>
<td>67.5</td>
<td>29.27</td>
</tr>
<tr>
<td>17</td>
<td>8000</td>
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<td>23.98</td>
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<td>14</td>
<td>8500</td>
<td>75</td>
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<td>17.42</td>
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<td>16</td>
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<td>70</td>
<td>20.92</td>
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<tr>
<td>1</td>
<td>10000</td>
<td>70</td>
<td>22.48</td>
</tr>
<tr>
<td>7</td>
<td>11000</td>
<td>75</td>
<td>20.56</td>
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<tr>
<td>5</td>
<td>12000</td>
<td>72.5</td>
<td>40.24</td>
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<tr>
<td>12</td>
<td>12000</td>
<td>72.5</td>
<td>23.42</td>
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<td>11</td>
<td>13000</td>
<td>75</td>
<td>25.45</td>
</tr>
<tr>
<td>3</td>
<td>13000</td>
<td>70</td>
<td>19.18</td>
</tr>
<tr>
<td>8</td>
<td>13000</td>
<td>55</td>
<td>23.73</td>
</tr>
<tr>
<td>6</td>
<td>13000</td>
<td>75</td>
<td>29.74</td>
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<tr>
<td>15</td>
<td>15000</td>
<td>67.5</td>
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<td>15000</td>
<td>70</td>
<td>28.93</td>
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<tr>
<td>19</td>
<td>23000</td>
<td>67.5</td>
<td>36.2</td>
</tr>
</tbody>
</table>
Figure 35. Pilot Accuracy as a Function of Flight Hours Experience

Figure 36. RT to Interpret Clearance as a Function of Flight Hours Experience
4.3 Experiment I Discussion

The purpose of this exploratory study was to obtain data and pilot feedback related to how pilots might create requests to ATC through DMs under complex clearance scenarios likely in NextGen. The results were intended for use in creating Human Factors recommendations for future DataComm interface design efforts. The design of the flight deck interface for DataComm used in this study was a step beyond the traditional CDU, but was still primarily based on text rather than graphics. Thus it represents an interim step for near and midterm implementation concepts. The findings of the HITL experiment are discussed below based on the type of data collected including RT, accuracy, and pilot feedback.

4.3.1 Percent Correct ATC Rejections and Accepts

Pilots correctly rejected clearances at a higher rate than accepting them. Pilots were very conservative and tended to reject more clearances than accept them, even if the rules were to accept for a given scenario. Pilots may have been thinking of other considerations based on their past experience when making decisions. Some issues pilots considered included passenger comfort, and physical capabilities and performance levels of the aircraft. Gallimore et al. (2013) also found that pilots correctly rejected more clearances than correctly accepting clearances.

4.3.2 Response Time to Interpret

As the number of elements in the clearance increased, the response time for pilots to interpret the clearance increased as well. Pilots took longer on the more
complicated clearances and this may also be the reason why the accuracy levels were higher because of the thoroughness factor.

**4.3.3 Age and Experience**

There were no trends or patterns when pilot experience levels were visually examined with respect to their effects on accuracy and RT (Figures 33 - 36). Initially, it was thought that pilots with more experience may have a better understanding of the clearances. However, this was not the case. Pilots with more experience did not do worse either. For example, the most experienced pilot had 23,000 flight hours experience and the accuracy scored was 68% correct. The least experienced pilot tested had 1500 flight hours experience and the accuracy was 70%.

Similarly, in regards to response time to interpret a clearance and overall accuracy, age did not provide any trends. The youngest pilot did ironically score the highest at 80%, and had the fastest response time. However, as the age increased the response time to interpret a clearance had no trend. High variance within the RT played a role affecting significant trends with regards to age.

**4.3.4 Errors with a Time-based Clearance**

One of the tested clearances made a potential source of pilot error apparent during analysis. The clearance was [UM76, UM339] which stated: “AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]” Once the scenarios were reexamined, it was determined that the pilots prematurely accepted the clearance just because the route brought the plane back onto the original flight plan (which was one rule for accepting a clearance).
However, the pilots should have rejected this clearance because the time used in this clearance was often an unacceptable time when it would not even be feasible. For this reason, it was determined that if RTA’s are used for future DataComm messages, an emphasis on the time graphic is vital. An error prompt for times not feasible may be necessary, especially for pilots when creating their own 4DT clearances in the future.

4.3.5 Excessive Input

Pilots did not like the number of button presses required to interact with the interface to create a DM. Every pilot stated that this was the most time consuming and labor intensive section of TextGen, and that a better method should be considered if the entire system is transitioning to a text-based method for communication.

Pilots did not like having to “Accept” each downlink message (DM) when concatenating DMs. The graphics for the DM were 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 were more familiar with an alphanumeric keypad. However, some pilots reported having recently adapting to using an iPad to access maps and perform navigation. These specific pilots felt that the QWERTY keypad was not an issue.
4.3.6 Partial Acceptance

The experimental instructions were to reject the entire clearance even if only one section of the clearance was unacceptable. Pilots had to create a request by reconstructing the entire message correcting the incorrect variables. 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 the clearance, and the possibility of introducing errors. Partial acceptance may be necessary if messages for DataComm become increasingly complex.

4.3.7 Error Prompting

There was no error checking in the experimental system. If a waypoint was spelled incorrectly pilots were not prompted. Pilots expected the system to ensure they did not make such a mistake. This feature is vital for future implementation.

4.3.8 Complex Clearances

The concatenated clearances were not always well accepted by pilots because they were not similar to current practice using voice. Voice clearances are usually one or two element messages requiring immediate execution, so there is little ambiguity regarding when to begin the clearance instructions. UMs were concatenated together and 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 knowledge of NextGen. The pilots that had knowledge regarding the concepts of NextGen realized that it was necessary for effective communication with ATC, especially once 4DT clearances and RTA’s are
introduced into the system. It was understood by this small group of pilots that this research was necessary to support the transition to more complex DataComm messages. However, many pilots did not feel that the current system (Voice Clearances) needs updating because they think it works well and did not see a reason for changing something that works.

4.3.9 Downlink Messages (DMs)

Pilots liked that the DM was supplied when creating the DM to ATC once rejecting the initial clearance. Pilots appreciated that the original text clearance remained on the screen for reference while constructing the DM.

4.3.10 Keypad Features

When pilots needed to make an input, the virtual keypad displayed keys to type variables. For numerical input, a number pad appeared. For the alphabet, a QWERTY keypad displayed. Pilots liked this concept. 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 latitude/longitude may be an input for TBOs in the NextGen NAS.

4.3.11 Specifying Units

Most UMs and DMs do not specify the units of measure. For example, UM 310: ‘After passing [position] maintain [speed]’ did not require knots after speed in the UM. When creating DMs, pilots did not necessarily recognize 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 units, thus pilots chose 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.

**4.3.12 Ergonomic Positioning**

The touch screen was not optimized for human use with respect to placement and resulted in hand or arm fatigue. This was noted by pilots. If touchscreens are used they must be placed in an ergonomic position based on the interface design. Implementation of advanced technology into the flight deck becomes a non-factor if pilots cannot interface with the device in an effective manner. Future research should address this issue and human factor recommendations should be developed.

**4.3.13 Graphics**

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.

**4.3.14 SC-214 Message Set**

The SC-214 text for DMs is not identical to the text for 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. The reason for this was because the experiment used authentic UM and DMs.
SC-214. It was not intended to create fictitious DMs, but it was necessary to provide options for pilots to respond to specific sections of the clearance upon rejection. Table 14 shows the UMs used in the evaluation and which DMs pilots selected as a response to the UM messages. The text is slightly different, but the context of the messages remains consistent.
<table>
<thead>
<tr>
<th>UM #</th>
<th>Uplink Messages (UMs)</th>
<th>Translates to . . .</th>
<th>Downlink Messages (DMs)</th>
<th>DM #</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/23</td>
<td>CLIMB TO [level] / DESCEND TO [level]</td>
<td>translates to . . .</td>
<td>REQUEST [level]</td>
<td>6</td>
<td>Issue</td>
</tr>
<tr>
<td>78</td>
<td>AT LEVEL [level single] PROCEED DIRECT TO [position]</td>
<td>translates to . . .</td>
<td>AT LEVEL [level] PROCEED DIRECT TO [Position]</td>
<td>x</td>
<td>Fiction</td>
</tr>
<tr>
<td>28</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]</td>
<td>translates to . . .</td>
<td>AT TIME [time] REQUEST [level]</td>
<td>13</td>
<td>No Problem</td>
</tr>
<tr>
<td>76</td>
<td>AT TIME [time] PROCEED DIRECT TO [position ]</td>
<td>translates to . . .</td>
<td>AT TIME [time] PROCEED DIRECT TO [Position]</td>
<td>x</td>
<td>Fiction</td>
</tr>
<tr>
<td>64</td>
<td>OFFSET [specified distance] [direction] OF ROUTE</td>
<td>translates to . . .</td>
<td>REQUEST OFFSET [specified distance] [direction] OF ROUTE</td>
<td>15</td>
<td>No Problem</td>
</tr>
<tr>
<td>65</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE</td>
<td>translates to . . .</td>
<td>AT [Position] REQUEST OFFSET [specified distance] [direction] OF ROUTE</td>
<td>x</td>
<td>Fiction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>REQUEST HEADING [degrees]</td>
<td>70</td>
<td>Not appropriate in exp</td>
</tr>
<tr>
<td>UM #</td>
<td>Uplink Messages (UMs)</td>
<td>Downlink Messages (DMs)</td>
<td>DM #</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>-----------------------</td>
<td>-------------------------</td>
<td>------</td>
<td>-------</td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>AT [position ATW] FLY HEADING [degrees]</td>
<td>translates to . . . AT [Position] FLY HEADING [Degrees].</td>
<td>x</td>
<td>Fiction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>translates to . . .</td>
<td>REQUEST DIRECT TO [position]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>68</td>
<td>REJOIN ROUTE BEFORE PASSING [position]</td>
<td>translates to . . . AT [position] REQUEST TO REJOIN ROUTE BEFORE PASSING [Position]</td>
<td>x</td>
<td>Fiction</td>
<td></td>
</tr>
<tr>
<td>188</td>
<td>AFTER PASSING [position] MAINTAIN [speed]</td>
<td>translates to . . .</td>
<td>18</td>
<td>Not appropriate in exp</td>
<td></td>
</tr>
<tr>
<td></td>
<td>translates to . . .</td>
<td>REQUEST [Speed]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>AT LEVEL [level single] MAINTAIN [speed]</td>
<td>translates to . . .</td>
<td>x</td>
<td>Fiction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>translates to . . .</td>
<td>AT [LEVEL] REQUEST [Speed]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.3.15 Pilot Feedback

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 feasible. 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.

The experiment was conducted with single pilots. Pilots stated that in real life situations the plane would have to be on autopilot, or it would be difficulty to interact with the interface and fly safely and smoothly.

Pilots, for the most part, appreciated the additional ND to interact with when creating 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 pilots felt that there was a learning curve to the interface, but once adapting to what they were expected to do, and rules for accepting or rejecting a clearance, 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 actually expected to carry out the clearance upon acceptance. Pilots stated that it would be vital to have the clearance remain within a log for reference.
5.0 Experiment II- AutoGen: A Direct-Manipulation DM Creation Interface

Experiment II was conducted to compare pilot performance using the text-based DM creation interface (TextGen) versus a direct-manipulation interface (AutoGen). AutoGen allowed pilots to create DM requests by altering clearances messages by manipulating the graphics using a touch and drag technique. Figure 37 and 38 illustrate TextGen and AutoGen. The AutoGen interface is described in detail later in this section.

![Figure 37. TextGen - DM Creation Interface utilizing a menu-based system to input variables](image1)

![Figure 38. AutoGen - DM Creation interface utilizing a direct-manipulation system. The variables in the DM are altered once the graphics are manipulated using a touch and drag technique](image2)
In addition to the comparison of TextGen and AutoGen, the TextGen condition was slightly altered in order to compare pilot performance when a DM graphic is not created compared to the condition in Experiment I where a graphic of the DM was displayed as the DM message was created by the pilot. This allowed a direct comparison between pilot performances using TextGen in Experiment I to TextGen in Experiment II. Table 15 lists the difference between Experiment I and II. The six clearances used in Experiment II were included in Experiment I so that a comparison could be made.

Table 15. Differences between Experiment I and Experiment II

<table>
<thead>
<tr>
<th>Experiment</th>
<th># of Subjects</th>
<th># of Scenarios</th>
<th># of Clearances per Scenario</th>
<th># of Total Clearances Tested</th>
<th>Downlink Message Creation Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>24</td>
<td>20</td>
<td>2</td>
<td>40</td>
<td>TextGen</td>
</tr>
<tr>
<td>II</td>
<td>8</td>
<td>8</td>
<td>3</td>
<td>24</td>
<td>TextGen / AutoGen</td>
</tr>
</tbody>
</table>
5.1 Hypotheses

5.1.1 TextGen With and Without DM Graphics

In Experiment I the TextGen interface used both text and graphics to depict DMs to the pilot before sending the DM to ATC. To compare text without graphics, Experiment II removed the graphic DM on TextGen for most of the scenarios. To determine if the DM Graphic improved performance, data from Experiment I was compared to data from Experiment II.

**Hypothesis 1:** DM Graphics depicted on the ND for TextGen will reduce the amount of time it takes the pilot to create a DM versus the condition of no DM Graphics.

The reason for this expectation is because, intuitively, DM Graphics will confirm pilot input more quickly. This graphic reassurance may decrease the pilot's overall cognition time, which will translate to quicker DM creation.

5.1.2 TextGen versus AutoGen

**Hypothesis 2:** Pilot response time to reject a clearance and create a DM will be faster using AutoGen versus TextGen.

The reason for this expectation is because AutoGen has automated features built into its interface. Pilots are not required to input any names of Waypoints, or VOR stations, via a keyboard as required for TextGen. The only input required by pilots on AutoGen is when inputting numbers for altitude, speed, and time variables.

**Hypothesis 3:** There will be no significant difference in mean response time to correctly accept a clearance between TextGen and AutoGen when comparing clearances with the same number of elements.
The reason for this expectation is because the overall structure of the experiments for both interfaces is similar. (The only difference is that AutoGen has a larger ND, and slightly larger buttons.) Therefore, the response time to correctly accept a clearance between both interfaces should not be significantly different.

**Hypothesis 4**: There will be no significant difference of accuracy (percent correct) between TextGen and AutoGen.

The reason for this expectation is because the overall structure of the experiments for both interfaces is similar. (The only difference is that AutoGen has a larger ND, and slightly larger buttons.) Therefore, the accuracy of pilots tested on both interfaces should not be significantly different between both interfaces when comparing the same clearances.

**5.1.3 Additional Data Analysis**

In addition to the objective measures of response time and accuracy pilots were asked their opinions of TextGen and AutoGen including their preferences.
5.2 Method II

5.2.1 Experimental Design

The experimental was a single factor within subject design with one Independent Variable, Presentation Format. The two levels of format were TextGen and AutoGen. AutoGen presentation format is described under Stimuli.

5.2.2 Dependent Variables

The DVs included the following:

1) Mean response time to correctly accept a clearance

2) Mean time to correctly reject a clearance and create a DM

3) Percent correct accepts (WILCO) and percent correct rejections (UNABLE)

5.2.3 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.

5.2.4 Apparatus

The HITL simulator described in Experiment I was used for this study.

5.2.5 Stimuli

5.2.5.1 Clearances

This study used six of the ten clearances used in Experiment I and are listed in Table 16. The six clearances were repeated four times resulting in 24 total clearances for each format condition (TextGen vs. AutoGen). Half of the scenarios
were designed such that the pilot should respond UNABLE. Half were designed so the pilot should respond WILCO. Three clearances were tested within a single flight scenario. The 8 separate flight scenarios were genuine flight paths in the United States and the ND provided information about airports, VOR (Very high frequency Omni-directional Range) stations, NDB (Non-Directional Beacons), and waypoints.

Table 16. Six clearances used during Experiment II

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

5.2.6 TextGen Interface for Creating DMs

The TextGen interface was identical to the interface described in Experiment I. The only difference was that when pilots created a DM, the graphic representation of the DM request was not shown in orange on the ND for most scenarios. This
difference was included so that the data collected in this experiment could be compared to data collected in Experiment I using the same format.

5.2.7 AutoGen Interface for Creating DMs

The AutoGen interface direct manipulation interface using a touch and drag technique for interaction. Instead of using categories and text to create the DM, the pilot was able to move the graphics on the ND to generate the DMs. The DM was then automatically created so pilots could read the text DM before accepting the message. Figures 37-41 illustrates the basic interface from arrival of a clearance through creation of the DM. Figure 37 illustrates the first phase upon receiving a clearance from the simulated ATC station. A magenta line showed the aircraft’s current flight path. The green line is the clearance instruction presented graphically while the text clearance was presented in green text in the window to the right of the ND. If a pilot rejected the clearance, the ND graphics updated with orange graphics. All original route and heading clearance graphics were overlaid with orange graphics. All numbers were re-stated in orange adjacent to the original clearance numbers. In the window below the ND, an orange DM text message is automatically created that matches the text clearance. The pilot could select different portions of the orange line or text on the graphic (such as altitude) using the touch from a finger. To adjust the route clearance, the node could be dragged and released anywhere on the ND to adjust the path. As the pilot moves the node to a VOR or other waypoint on the ND, the system would automatically lock onto them. The orange DM text visually updated real time when the waypoint was selected so the pilot could release the node. If there was no VOR or waypoint nearby, and the
pilot released the line, the system would calculate the Latitude/Longitude of that position and insert in the DM text. It must be noted that for this experiment the concept was to create a DM based on the ATC clearance. It was not possible to create an additional DM that was different than the original clearance structure. For example, if the pilot wanted to concatenate the message with a speed request, it would not be possible. The clearance structure is fixed. Only variables within the clearance can be altered after rejection. A hybrid approach between TextGen and AutoGen would be needed to create this flexibility.

Figure 37. Initial text and graphic clearance that appears when the experiment began. The pilot analyzed the clearance in reference to the dynamically changing variables.
Figure 38. Screenshot of the interface after the pilot selects ‘UNABLE’. The green text clearance is repeated verbatim in the DM creation section in orange. Orange graphics (route & heading) overlay the green graphics on the ND.

Figure 39. Orange routing graphics have been altered by touching and dragging an orange node to a new position. DM text is automatically updated. The heading was also altered and also updates automatically in the DM text section.
Figure 40. The pilot selected the variable time. The number pad appears to allow pilot input for alteration.

Figure 41. Time and altitude have been altered
5.2.8 Procedure

Subjects first participated in the TextGen condition followed by AutoGen. Pilots were trained using two practice trials for each format, which included six separate clearances illustrating all clearance possibilities. Pilots were also provided the rules for accepting and rejecting a clearance which are provided in Table 3 under Experiment I. Upon completion of training pilots participated in the experiment for approximately two hours. Within each format the scenarios were randomized for each subject. Upon completion of trials, pilots shared their opinions about the interfaces, and were then debriefed and thanked for their participation.
5.3 Experiment II Results

5.3.1 Response Time

5.3.1.1 Time to Create DM - TextGen With & Without DM Graphics

Six of the ten clearances from Experiment I were included in Experiment II. For this analysis data from Experiment I was compared to data in Experiment II. The raw data were imported into excel files and descriptive statistics were calculated using JMP Pro 10.0.1 Release 2. In Experiment I a graphic of the DM was drawn as the pilot created the DM. The pilot could review the graphic before they sent the message. To compare graphic DM versus no graphic DM, Experiment II did not include graphics for DM creation under the TextGen format. To evaluate time to create a DM with and without DM graphics on TextGen a non-parametric test, the Kruskal-Wallis (KM) One-Way ANOVA, was conducted. A non-parametric test was chosen because the data were not normally distributed. The RT includes both response times to reject and time to create a DM as a combined total value. The test showed no significant difference in response time for creating a DM with and without graphics (p=0.78). Figure 42 presents the mean response time to correctly reject a clearance and create a DM with and without DM graphics for TextGen. The difference is only on the order of 4 seconds. Table 17 provides the summary statistics.
Table 17. Summary Statistics for Mean Time to Create a DM with and without DM Graphics for TextGen

<table>
<thead>
<tr>
<th>Condition</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>With DM Graphics</td>
<td>167</td>
<td>114.22</td>
<td>47.68</td>
<td>3.69</td>
<td>107.45</td>
<td>122.02</td>
<td>42.65</td>
<td>334.03</td>
</tr>
<tr>
<td>Without DM Graphics</td>
<td>59</td>
<td>118.43</td>
<td>56.29</td>
<td>7.33</td>
<td>106.53</td>
<td>135.87</td>
<td>49</td>
<td>392</td>
</tr>
</tbody>
</table>

5.3.1.2 DM Creation

The mean times were calculated for DM creation for both TextGen and AutoGen 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 AutoGen the KW non-parametric test was conducted.

Figure 43 illustrates the mean time to create a DM for both Formats. The Kruskal-Wallis test was statistically significant at $p \leq .0001$. Pilots using AutoGen
were able to create a DM in significantly less time than when using TextGen. Table 18 presents the summary statistics for both formats.

![Figure 43. Mean Time to Reject a Clearance and Create a DM](image)

**Table 18. Summary Statistics for Mean Time to and Create a DM**

<table>
<thead>
<tr>
<th>Format</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>TextGen</td>
<td>57</td>
<td>113.67</td>
<td>38.27</td>
<td>5.07</td>
<td>103.51</td>
<td>123.82</td>
<td>49.00</td>
<td>232.00</td>
</tr>
<tr>
<td>AutoGen</td>
<td>88</td>
<td>43.11</td>
<td>18.72</td>
<td>2.00</td>
<td>39.15</td>
<td>47.08</td>
<td>13.00</td>
<td>105.00</td>
</tr>
</tbody>
</table>

**5.3.1.2 Response Time to Correctly Accept a Clearance**

The clearances were divided into three separate categories based on number of elements (4 elements, 5 elements, and 6 elements). The mean response time for each element category were individually analyzed for each format. The standard deviation, standard error, and confidence intervals were recorded and are displayed in Table 19 for TextGen and Table 20 for AutoGen. To evaluate response time
between TextGen and AutoGen the KW non-parametric test was conducted because the data are not normally distributed, the variances were large, and there were unequal N.

For four element clearances there was no significant difference in mean response time between TextGen and AutoGen to correctly accept a clearance \( (p=0.33) \). Figure 44 displays the results.

For five element clearances there was a significant difference in mean response time between TextGen and AutoGen to correctly accept a clearance \( (p=0.0179) \). Figure 45 displays the results.

For six element clearances there was significant difference in mean response time between TextGen and AutoGen to correctly accept a clearance \( (p=0.0010) \). Figure 46 displays the results.

![Figure 44. Response Time to Correctly Accept a Clearance separated for 4 Elements](image-url)
Table 19. Summary Statistics for Mean Response Time for Correctly Accepting a Clearance by Number of Elements for TextGen

<table>
<thead>
<tr>
<th>Clearance Complexity</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Element</td>
<td>13</td>
<td>25.11</td>
<td>15.04</td>
<td>4.17</td>
<td>16.02</td>
<td>34.19</td>
<td>6.43</td>
<td>60.2</td>
</tr>
<tr>
<td>5 Element</td>
<td>37</td>
<td>27.94</td>
<td>21.4</td>
<td>3.52</td>
<td>20.79</td>
<td>35.08</td>
<td>8.51</td>
<td>124.67</td>
</tr>
<tr>
<td>6 Element</td>
<td>15</td>
<td>50.69</td>
<td>36.11</td>
<td>9.32</td>
<td>30.69</td>
<td>70.69</td>
<td>14.35</td>
<td>151.32</td>
</tr>
</tbody>
</table>
Table 20. Summary Statistics for Mean Response Time for Correctly Accepting a Clearance by Number of Elements for AutoGen

<table>
<thead>
<tr>
<th>Clearance Complexity</th>
<th>Number of data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Element</td>
<td>14</td>
<td>20.91</td>
<td>13.85</td>
<td>3.70</td>
<td>12.91</td>
<td>28.91</td>
<td>9.03</td>
<td>63.15</td>
</tr>
<tr>
<td>5 Element</td>
<td>42</td>
<td>18.67</td>
<td>10.19</td>
<td>1.57</td>
<td>15.49</td>
<td>21.84</td>
<td>7.79</td>
<td>54.75</td>
</tr>
<tr>
<td>6 Element</td>
<td>18</td>
<td>22.02</td>
<td>13.12</td>
<td>3.09</td>
<td>15.49</td>
<td>28.54</td>
<td>8.77</td>
<td>69.64</td>
</tr>
</tbody>
</table>

5.3.1.3 Mean Response Time to Correctly Accept a Clearance

Figure 47 presents the mean response time to correctly accept a clearance regardless of number of elements. The Kruskal-Wallis test was statistically significant at $p < 0.001$. TextGen resulted in significantly slower response times to correctly accept a clearance than AutoGen. Table 21 lists the summary statistics.

![Figure 47. Mean Response Time for Correct Accept for TextGen and AutoGen](image-url)
Table 21. Summary Statistics for Mean Response Time for Correct Accept as a Function of Presentation Format

<table>
<thead>
<tr>
<th>Format</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>TextGen</td>
<td>59</td>
<td>34.38</td>
<td>26.75</td>
<td>3.48</td>
<td>27.41</td>
<td>41.35</td>
<td>8.51</td>
<td>151.32</td>
</tr>
<tr>
<td>AutoGen</td>
<td>74</td>
<td>19.91</td>
<td>11.61</td>
<td>1.35</td>
<td>17.21</td>
<td>22.60</td>
<td>7.79</td>
<td>69.64</td>
</tr>
</tbody>
</table>
5.3.2 Accuracy

In addition to response times, accuracy was also recorded in Experiment II. Accuracy was defined as the percentage of clearances correctly accepted and percentage correctly rejected. The summary statistics for pilot accuracy are displayed in Table 22.

Table 22. Summary Statistics for Pilot Accuracy as a Function of Presentation Format

<table>
<thead>
<tr>
<th>Format</th>
<th>Number data pts</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Err</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
<th>MIN</th>
<th>MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>TextGen</td>
<td>8</td>
<td>0.81</td>
<td>0.054</td>
<td>0.022</td>
<td>0.762</td>
<td>0.853</td>
<td>0.75</td>
<td>0.875</td>
</tr>
<tr>
<td>AutoGen</td>
<td>8</td>
<td>0.848</td>
<td>0.074</td>
<td>0.026</td>
<td>0.787</td>
<td>0.910</td>
<td>0.70</td>
<td>0.916</td>
</tr>
</tbody>
</table>

The KW test indicated there was no significant difference between TextGen and AutoGen with respect to pilot accuracy (p = 0.18). Figure 48 displays the similarity in accuracy levels between presentation formats.

Figure 48. Pilot Accuracy for TextGen and AutoGen
5.3.2.1 Mean Percent Correct to Accept or Reject a Clearance

Figure 49 illustrates the mean percent correct accepts and rejects for TextGen and AutoGen. Table 23 presents the summary statistics. The Kruskal-Wallis test was conducted for correct accepts and correct rejects. There were no significant differences between TextGen and AutoGen for Correct Accepts, $p = 0.06094$, nor Correct Rejects, $p = 0.91$. Pilots correctly rejected clearances with fewer errors than correctly accepting them. However, note that the percentage of correct accepts are lower than correct rejects similar to the Gallimore et al (2013) study. The previous section showed no difference between accepts and rejects for TextGen and AutoGen because when averaging across correct accepts and correct rejects for each condition the means are similar.

![Figure 49. Mean Percent Correct Accepts and Rejections as a Function of Presentation Format]
Table 23. Summary Statistics for Mean Percent Correct Accepts and Correct Rejections as a Function of Presentation Format

<table>
<thead>
<tr>
<th>Pilot Answer</th>
<th>Accept</th>
<th>Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TextGen</td>
<td>AutoGen</td>
</tr>
<tr>
<td>Correct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Answer</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accept</strong></td>
<td>Mean = 74.00%</td>
<td>Mean = 77.08%</td>
</tr>
<tr>
<td></td>
<td>Std Dev = 44.28</td>
<td>Std Dev = 42.25</td>
</tr>
<tr>
<td></td>
<td>CI: 63.90 &amp; 83.60</td>
<td>CI: 68.52 &amp; 85.64</td>
</tr>
<tr>
<td><strong>Reject</strong></td>
<td>Mean = 7.81%</td>
<td>Mean = 7.29%</td>
</tr>
<tr>
<td></td>
<td>Std Dev = 27.05</td>
<td>Std Dev = 26.13</td>
</tr>
<tr>
<td></td>
<td>CI: 85.43 &amp; 98.94</td>
<td>CI:87.41 &amp; 98.00</td>
</tr>
</tbody>
</table>
5.4 Experiment II Discussion Section

The purpose of this study was to obtain data and pilot feedback related to how pilots might create requests to ATC through DMs, similar to Experiment I, under complex clearance scenarios likely in NextGen. The results were used to create Human Factors recommendations. Pilot Feedback from Experiment I helped develop the features and capability for AutoGen.

Two separate interface formats were tested; TextGen and AutoGen. These interface formats were compared against one another based on accuracy, response times, and pilot comments. Four separate hypotheses were developed for analysis. The only hypothesis that compares data from Experiment I is Hypothesis 1. All other hypotheses utilized data from Experiment II. The findings based on the HITL experiment are discussed below and separated by each hypothesis. Pilot feedback is also presented.

**Hypothesis 1** - DM Graphics depicted on the ND for TextGen will reduce the amount of time it takes the pilot to create a DM versus the condition of no DM Graphics.

The results indicated that there was no significant difference in mean time to create a DM with and without DM graphics using TextGen. It was expected that DM graphics would support pilots when creating the DM in comparison to the original text for each specific clearance. However, even though the pilots preferred the DM graphics, and the graphics did provide assurance that their inputs were correct, the graphics did not necessarily decrease the amount of time took to create the DM. The
manner in which each pilot interacted with the interface was still the same regardless of whether the DM graphics appeared on the ND or not. The same number of button presses were required when selecting different messages and inputting variables. They were still required to input waypoints, altitudes, speeds, and times. Therefore, even though pilots preferred DM graphics, they did not significantly decrease the amount of time that it took for them to create a DM.

All 24 pilots in Experiment I saw DM graphics for the six clearances. There were unequal N, and this was accounted for. However, for Experiment I when pilots were asked if the DM graphics helped create the DM, all 24 pilots responded “Yes” with absolute certainty. When all eight pilots were asked if the DM graphics helped to create a DM after Experiment II, all pilots responded “Yes” with absolute certainty. To be clear, pilots in Experiment II did not see DM graphics for the six clearances specified in the experiments.

**Hypothesis 2** – Pilot response time to reject a clearance and create a DM will be faster using AutoGen versus TextGen.

The results showed that pilots could create a DM significantly faster using the direct manipulation interface (AutoGen) versus the menu-based (TextGen). This is due to the automatic generation of input variables for AutoGen compared to selecting DMs from categories and inputting variables manually with a keypad. All pilots appreciated the automation features that AutoGen provided and all eight pilots preferred AutoGen over TextGen.
Hypothesis 3 – There will be no significant difference in mean response time to correctly accept a clearance between TextGen and AutoGen when comparing clearances with the same number of elements.

This data were divided into three separate categories since there were three groups for number of elements. For four element clearances there was no significant difference in pilot response time to correctly accept a clearance between TextGen and AutoGen. This result was expected because the scenario structure was similar between the two formats.

However, for five and six element clearances there was a significant difference in RT to correctly accept a clearance. AutoGen allowed pilots to respond faster when comparing the same clearances. It is possible that there could have been an ordering effect because each pilot was exposed to TextGen first. Another possibility is the difference in graphic display size. AutoGen did have larger buttons and a larger ND. TextGen had an ND measuring 15.25 cm high x 12.57 cm wide. AutoGen had an ND measuring 18.10 high x 18.41 wide. The buttons for TextGen were 1.12 cm high x 3.49 cm wide. The buttons for AutoGen were 1.27 cm high x 6.03 cm wide. The waypoints, VOR stations, and clearance graphics presented on AutoGen were spaced farther apart. These differences may have contributed to faster cognitive processing for the pilot as the clearances became more complex.

Hypothesis 4 – There will be no significant difference of accuracy (percent correct) between TextGen and AutoGen.

The results indicated that there was no significant difference between TextGen and AutoGen with respect to accuracy (overall percentage correct). This
result was also expected. Both formats were conducted under similar conditions with regard to clearance structure, reasons for accepting and rejecting a clearance, and graphics depicted on the ND. The only differences were the size of the buttons and ND graphic, as stated previously. These differences were not enough to affect how accurate pilots were at judging whether a clearance was acceptable. However, there was a difference for correct accepts and correct rejections. When pilots were confused on clearances, or unsure, the clearances were typically rejected. Whenever there was anything wrong at all, even one incorrect variable, pilots were instructed to reject the clearance during practice trials. Although there was no significant difference between both interfaces with respect to accuracy, there was a slight difference. Pilots tended to reject clearances correctly slightly more often. This result was similar to previous finding from other research testing alternate DataComm interfaces (Gallimore et al., 2013).

**Pilot Comments**

All pilots were debriefed after the experiment and asked the same nine questions. The feedback, regardless of experience and class, (GA, private, or military), was consistent. All eight pilots stated that the direct-manipulation interface (AutoGen) was preferred to the menu-based interface (TextGen). Pilots appreciated that the DMs were automatically created once the clearance was rejected. Pilots thought that the manipulation of the graphic on AutoGen was intuitive and appreciated the text DM updating in real time in conjunction with their direct manipulation of the graphics.
- Pilots also liked 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 updated within the DM section.

- For both TextGen and AutoGen, pilots liked how the original clearance remained on the ND for reference.

- Some military pilots did state that there may be a concern regarding turbulence that could potentially affect their ability to use a touch screen.

- The AutoGen interface was designed to respond directly to incoming clearances. There was no ability to create an additional request. Because pilots in this study also used TextGen, it was noted that AutoGen would need the ability to create requests that were not based on the clearance (as with TextGen). An interface that is a hybrid of TextGen and AutoGen would be needed to capitalize upon benefits from both systems.
6.0 Overall Discussion Section

DataComm is an evolving technology that will continue to adapt in order to meet the demands of NextGen for the NAS. Advanced features will supplement the current communication systems to alleviate WL for ATC, pilots, and all stakeholders involved. Graphics implemented on current NDs would likely improve the efficiency of communication (Gallimore et al., 2013). Lee (2011) stated that graphical representations of 4DT clearances between ATC and the pilot would significantly enhance coordination tasks. DataComm will ultimately provide the opportunity to improve data flow between pilot and ATC. Features pertaining to DataComm vary, and many factors play a role including implementation cost, and time for research and development. DataComm implementations are not likely to drastically change overnight. Instead, small implementations will occur slowly over time. The system will continuously adapt as needed in phases.

While DataComm is being developed out of necessity, the system should not decrease pilot performance and SA upon initial implementation. Hoey et al. (2002), Shelton et al. (2009), van Marwijk et al. (2010), and Johnson et al. (2010) have performed research on graphic display formats for NextGen and their results illustrate that future operations will be complex and require graphic presentations to support pilot operations. Graphics depicted on the ND in conjunction with the text could alleviate some potential implementation problems. Graphical depictions of RTA and 4DT clearances improve the capability of pilots within the flight deck. The results of this study support that graphical depiction of complex clearances could help pilot perception when executing clearances at specific times and
locations. However, in one clearance specifically related to time, pilots did not successfully perceive time specified in the text. Presenting the time adjacent to the position on the ND was adequate only when the time was accurate. If the time was purposefully incorrect (for design purposes), and the route clearance to accompany the time aspect of the clearance correctly brought the pilot back onto their original route, pilots responded incorrectly.

An innovative communication interface is essential for DataComm within NextGen. The TextGen interface was developed as a simple format for pilots to utilize when communicating with ATC and developing DMs from scratch. The results indicated that excessive input was required. This result was not anticipated because the interface was designed to minimize input. However, after one pilot completed the study, it was quickly realized how labor intensive the tasks became. The DM messages were provided in categories, so pilots did not have to create the messages from scratch. However, the input of variables alone still proved to be challenging, labor intensive, and error prone. The primary reason for added input was that pilots were required to select ‘Accept’ after each DM component so that experimental software could draw the graphics. This input is not needed and would eliminate a significant amount of input required. TextGen demanded 100% of the pilots’ attention. DM Graphics also did not improve pilot time to create a DM because all inputs were still necessary to create the DM message. Many lessons were learned from the initial exploratory study, and these lessons translated to the development of the Pilot/ATC communication interface for Experiment II.
AutoGen was considered effective by pilots, and resulted in faster DM creation times compared to TextGen. Direct graphical manipulation resulted in a quick learning curve. AutoGen automatically created the DM message for the pilot upon rejection, and the variables within the DM text were automatically altered once the graphics were manipulated on the touch and drag section of the ND. However, for this experiment new messages could not be added to the existing message structure. A complete interface would be a hybrid version of TextGen and AutoGen to include the ability to respond to ATC and initialize the communication to ATC through requests. TextGen did provide flexibility to create whatever message pilots desired even if it was different from what was included in the original clearance. If categories were available to the pilot on the AutoGen interface to provide the option to add or change a DM altogether, then this flexibility would be beneficial. These features combined into one interface along with voice as a backup system would be an excellent starting interface for further testing of DMs aiding DataComm research for future implementation.
7.0 Human Factors Recommendations

The results of this research helped develop fourteen Human Factors Recommendations related to Pilot/ATC communication interfaces. These recommendations could be applied to future DataComm interfaces within the NAS for NextGen. Even though the recommendations are based on the interfaces developed for the research, the same issues/concerns are relevant for alternate designs. Clearance representation of concatenated messages, both via text and graphics for uplink and downlink messages, are the focus for many of the recommendations. Each recommendation is presented in a Table that includes the general recommendation followed by rationale and examples when needed.

<table>
<thead>
<tr>
<th>Number 1</th>
<th>Category: DM Graphics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title:</strong> Graphic DMs</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong> The opportunity to review the downlink message via graphics and text should be provided during DM creation and before the pilot “sends” the DM message.</td>
<td></td>
</tr>
<tr>
<td><strong>Rationale:</strong> As the pilot creates a DM the system should build a graphic representation. The graphic should be created as each DM is added when messages are being concatenated. That is, the pilot should be able to visualize the graphic of each individual DM as creation occurs until the last DM is added. The text of the created DM should also be included so that the pilot can compare the text message with the graphic. This allows pilots to double check and provides necessary redundancy.</td>
<td></td>
</tr>
<tr>
<td>Figures 50 and 51 provide an example illustration of a graphic DM being drawn as the DM is created. With this example, the pilot selects a category for the DM, selects the DM, and then enters the variable related to the scenario.</td>
<td></td>
</tr>
</tbody>
</table>
Figure 50. TextGen Phase After Rejection

Graphics depicting the text clearance in green

Text Clearance in green

This clearance is a concatenation of 3 separate UM's
DM graphics show up in orange according to the message that the pilot is creating in the DM message creation section.

Figure 51. TextGen Phase after DM Creation
<table>
<thead>
<tr>
<th>Number</th>
<th>Category: UM Visibility after WILCO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title: UMs remain visible after they are accepted (WILCO)</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong></td>
<td>If the pilot accepts (WILCO) a UM, the clearance must remain visible so that the pilot may carry out the clearance. If the pilot has accepted the clearance, then an indication that the message has been accepted should be provided within the graphic and text of the message. Possible indications could be a change in color, or an indicator next to the message. The UM message should only be cleared from the DataComm display by the pilot.</td>
</tr>
<tr>
<td><strong>Rationale:</strong></td>
<td>Automatically deleting the clearance after it is accepted does not support the pilot’s mental WL. During experimentation all pilots noted the importance and value of referencing the clearance after it was accepted to support effect communication in real world applications. Since current aircraft have limited auto load capabilities into the FMS system, it is important to keep the message visible so it can be accurately entered via the CDU.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Category: UM and DM History Logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title: Logging UMs</td>
<td></td>
</tr>
<tr>
<td><strong>Recommendation:</strong></td>
<td>After a pilot accepts (WILCO) and executes the clearance, AND the pilot has selected to clear the primary DataComm message, the UM should be moved to a text log with most recent UMs showing first. All DMs should be cleared from the primary DataComm message display after the pilot selects ‘Send’. The DM should be moved to a text log with the most recent DM showing first as depicted in Figures 52 and 53.</td>
</tr>
</tbody>
</table>

![Figure 52. ATC / Pilot Messages Sent and Received - Split Mode](image)
Rationale: All pilots have stated that it is necessary to have a history of their conversation with ATC to reference once the text clearance is responded to. (Especially if the pilot is expected to physically carry out the clearance.)
Number 4  | Category: UM Graphics
---|---

**Title:** UMs remain visible after Rejection

**Recommendation:** The graphic and text UM should remain visible after the pilot rejects the clearance so that the message can be referenced when replying using DMs.

**Rationale:** Pilots noted that being able to view the original clearance supported their ability to create a downlink message in order to negotiate because they were able to correct the variables instructed to reject (Figure 54). Note that for this experiment accepting only part of a clearance was not permitted. Pilots were required to enter the entire clearance again, upon rejection.

---

**Figure 54. TextGen Phase After Rejection**
Number 5 | Category: DM Input Information
---|---
**Title:** Reduce types of input to only those possible.

**Recommendation:** When the DM requires pilots to input a variable that is a number, only a number keypad entry should be available. If the input requires letters, only a letter keypad should be available.

**Rationale:** To prevent pilots from inputting incorrect values, provide only the type of input that is acceptable when possible (Figure 55 and 56). This reduces the need for additional error checking algorithms. Pilots did not like the numbers provided in Figure 55 when waypoints or VOR stations were the expected entry.

![Figure 55. Keyboard that Appears when Pilots Input Waypoint Names or VOR Stations](image)

![Figure 56. Number Pad that Appears when Pilots Input Altitudes, Times, Headings, and Speeds](image)
Number 6  
Category: Selecting DMs  

**Title:** Techniques for selecting DMs

**Recommendation:** Commonly used DMs or concatenated DMs, such as the route DMs depicted in Figure 57, should be available in separate menus to limit pilot input.

![Figure 57. Six Categories that Appear to Create DM](image)

**Rationale:**
Given the large number of possible DMs and the concatenation of DMs, commonly used DMs or concatenated DMs should be available so that the pilot could make only minimal inputs. To select and concatenate DMs, the large number should be subdivided into understandable categories. Categories used for this research included the following:

- Altitude
- Time
- Offset
- Speed
- Route
- Heading
**Recommendation:** Consider specifying units for some textual UM and DMs to clarify meaning.

**Rationale:** Most UM and DMs do not specify the units of measure because the variables are considered to be part of the text. For example, the clearance in Figure 58 states ‘AFTER PASSING ISUZU MAINTAIN 300’. Pilots did not necessarily know that 300 meant 300 knots (Even though it specifically stated ‘knots’ on the ND). When pilots tried to correct this UM, a misunderstanding of the unit occurred at times, thus prompting pilots to choose a category for the DM creation unrelated to speed. The message becomes irrelevant. Most pilots interpreted the 300 as an altitude, referring to a specific flight level without giving it a second thought.

*Figure 58. TextGen Phase Demonstrating an Emphasis on Consistently Displaying Units*
**Recommendation:** Create additional DMs to provide pilots with more options when replying to specific UMs.

**Rationale:** In the experiment, of the sixteen different Uplink Messages (UMs) that were used for clearance construction, there were sixteen different Downlink Messages (DMs) that were provided for the pilots to use. Of those sixteen DMs, seven of them were fictitious. In other words, the DMs were created for the experiment because they were not currently in the RTCA SC-214 message set. In some cases the word 'REQUEST' was inserted with the UM when creating the corresponding DM. Other times a word within the clearance was replaced with the 'REQUEST'.

For example, the UM:

"AT TIME [time] PROCEED DIRECT TO [position]” …

… Does **NOT** have a corresponding DM to respond to it. Therefore, a DM had to be created that simply states:

"AT TIME [time] **REQUEST** DIRECT TO [position]”.

The word ‘REQUEST’ was added in place of the word ‘PROCEED’ to place as the pilot’s perspective when negotiating with ATC. This is indicated in Figure 59.
The seven DMs that were created for the experiment were:

1. AT LEVEL [level] PROCEED DIRECT TO [position]
2. AT TIME [time] PROCEED DIRECT TO [position]
3. AT [position] REQUEST OFFSET [specified distance] [direction] OF ROUTE.
4. AT [position] FLY HEADING [degrees]
5. REQUEST TO REJOIN ROUTE BEFORE PASSING [position]
6. AT [position] REQUEST [speed]
7. AT [level] REQUEST [speed]
**Recommendation:** Automatically populate the DM creation section once the clearance is rejected.

**Rationale:**
Pilots would only be required to change what they dislike once the clearance was rejected. This would limit physical input, limit input errors, and save time while alleviating cognitive WL.

---

**Figure 60. Phase of AutoGen after Pilot Responds with an Unable**
The DM is automatically created verbatim in the section below the ND in Figure 60. All the graphics corresponding to the original clearance are replicated in orange and overlaid on the green graphical clearance, waiting for the pilot to physically touch the graphic to manipulate the route or change altitude.
Recommendation: When graphically depicting the meaning of the clearance “Rejoin Route”, it is more effective to insert a horizontal line, and triangular shaded region on the ND, to minimize ambiguity between graphic and text.

Rationale:

Almost every pilot tested expressed concerns regarding the rejoin route clearance. Pilots stated that the graphics were inconsistent with the text route message depicted in Figure 61. Pilots stated that current standard protocol allows aircraft to rejoin the route at their discretion, and not be required to rejoin at a specific position. Pilots also prefer to rejoin their route immediately when receiving a rejoin, so instead of following the suggested graphic in Figure 61, the pilot would rather rejoin their route the instance their aircraft is 30 miles from their flight path. Based on this logic, pilots would technically be adequately complying with the text clearance; just not the graphic.

Figure 61. Example Graphic Display of Rejoin Route Clearance
To help alleviate ambiguity, a horizontal line is placed directly though the position that is addressed in the clearance. This provides a clear and definitive clearance limit. It will also help to alleviate ambiguity by inserting a green triangular shaded region to allow the pilot to rejoin at the path of their discretion as long as it resides within the boundary graphically depicted in Figure 62. Another solid green triangle is inserted to specifically state where the pilot needs to begin the execution of that segment of the clearance. The solid green triangle on the ND directly corresponds with the solid green triangle on the text section.

Implementing a horizontal line, a shaded green triangular region, and a solid green triangle on the ND increases the consistency of the graphics in relation to the meanings portrayed in text. Ambiguity is reduced once graphical meanings are known by pilots.

Figure 62. Alternative Graphic Display of Rejoin Route Clearance
<table>
<thead>
<tr>
<th>Number 11</th>
<th>Category: Zoom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Title</td>
<td>Zoom Labels</td>
</tr>
</tbody>
</table>

**Recommendation:**
Always depict waypoint and VOR names referenced in the clearance to remain visible on the ND regardless of the zoom level.

**Rationale:** Review the following three screenshots.

![Image](image.png)

**Figure 63. Phase of AutoGen before Pilot Responds with a Wilco or Unable**

The referenced VOR in Figure 63 is ‘PUC’. It is graphically depicted and circled above. This example does not prove the original recommendation, but is provided to show that the VOR station referenced in the clearance is clearly depicted on the navigation display.
Figure 64. Phase of AutoGen Display after Pilot Responds with an Unable

PUC is still somewhat visible even though it is slightly blocked by the graphics in Figure 64.
PUC is not depicted on the navigation display in Figure 65 because the software only displays the names of the filed waypoints instead of airports, VOR stations, other waypoints, and NDBs when greater than 160 nautical miles. This is an effort to reduce the amount of clutter on the display. (The zoom level in the above figure is set to 320 nautical miles.) The graphics clearly show that once the plane hits FL190 the aircraft needs to proceed direct to a point, and then fly a heading. The pilot’s first instinct is to confirm that the point referenced via graphics on the ND is actually ‘PUC’ referenced in the text clearance. Pilots are then required to manipulate the zoom level on the X-Plane monitor to decrease the range. The feature of de-cluttering the display when zooming out is well accepted, but pilots simply prefer the referenced point in the clearance to remain on the ND regardless of the zoom level. This implementation would alleviate ambiguity.
Figure 66. Phase of AutoGen Display after Pilot Responds with an Unable

Because of the zoom level, the point referenced in the clearance section is still not visible on the ND (Figure 66) even after the pilot has rejected it.
Recommendation:
Allow the variables displayed in the DM creation section to be active in addition to the orange DM graphics depicted on the ND.

Rationale: Only the ND is touch interactive, but pilots often attempted to touch the variables circled in Figure 67 to alter the variables upon rejection of the initial clearance. Both sections should be interactive.

Figure 67. Phase of AutoGen Display after Pilot Responds with an Unable
<table>
<thead>
<tr>
<th>Number</th>
<th>Category</th>
<th>Title</th>
<th>Recommendation</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>Zoom</td>
<td>Custom Zoom Level</td>
<td><strong>Recommendation:</strong> Allow the pilot to input their custom zoom level to the navigation display interactively.</td>
<td><strong>Rationale:</strong> When interacting with AutoGen pilots attempted to use their thumb and index finger to zoom, similar to interacting with tablets and smartphones. This capability was not provided to the pilots in the experiment. All pilots stated that that thumb-finger pinch movement would be nice to have. Many pilots stated that turbulence will always be an issue, but the interface itself would be intuitive if implemented.</td>
</tr>
<tr>
<td>14</td>
<td>Errors</td>
<td>Error Prompting</td>
<td><strong>Recommendation:</strong> Have an error prompt appear with an auditory and visual warning if waypoint names are incorrectly spelled by the pilot during input, or if the waypoint in the clearance is not near to the current location of the aircraft.</td>
<td><strong>Rationale:</strong> Pilots often misspelled waypoint names when using TextGen which included a keypad. Pilots more often than not caught their mistakes, and cleared their incorrect entry then corrected the spelling. However, not all errors were caught and the clearance was sent with the incorrect information.</td>
</tr>
</tbody>
</table>
8.0 Significant Contributions

Research conducted to complete this thesis has had significant contributions to the aviation community within DataComm research. Many private sector companies, government agencies, and research institutions are focusing on near-term implementation, but this research took a step beyond focusing on DM creation interfaces for midterm implementation with NextGen. Many individual contributions have been identified, summarized, and listed in bullet form below to provide perspective.

- Developed a study to evaluate how pilots may communicate with ATC via DataComm Downlink Messages
- First study to evaluate graphic and non-graphic techniques for creating DMs
- Developed a dynamic DataComm simulator that includes the ability to send DataComm clearances using the SC-214 message set at any time during a flight. It will allow for continued testing of DataComm issues as well as continued research into the use of graphics. The simulator is easily configurable, and used to evaluate multiple conditions from ATC clearances and DMs.
- Developed 14 Human Factors Recommendations regarding DMs, graphic implementations, and UMs
- Obtained baseline data for single pilot testing that can be used as data for comparison with other studies involving two pilots for communication.
- Gained valuable input and verbal feedback from pilots with significant experience.
Developed two separate Pilot/ATC communication interfaces with both implementing DM and UM graphical implementation. Each interface used touchscreens and pilots were able to create DMs. One interface created DMs via selecting messages from categories, and the second from direct graphic manipulation.

9.0 Future Research

Air-Ground DataComm is a currently operational technology and more advanced applications will continue to be implemented for NextGen in the NAS. TBO clearances and future RTAs provide many challenging and difficult human factors problems to solve. Significant research is necessary to efficiently and effectively support the transition from voice to digital communication.

This study evaluated communication interfaces for creating DMs under the condition of a single pilot in order to begin developing recommendations for the use of graphics for DMs. DataComm will be implemented in the near and midterm primarily in commercial aircraft with two pilots. Coordination and communication between the pilot and copilot, and procedures for clearance acceptance and DM creation during flight, needs to be investigated while using DataComm interfaces.

While the direct manipulation interface supports pilot DM creation, the design must also include the ability for the pilot to provide input for any variable through some type of keypad input. In other words, a hybrid approach between TextGen and AutoGen would be beneficial to test. Such a design must be created and evaluated under realistic flight scenarios. The current simulator used for this study could be altered and used for testing.
An issue related to DM creation is that the DMs in the SC-214 Message Set do not directly match the UMIs within the same document. In other words, most DMs were created to make sense from the pilot’s perspective. For example, many DMs have the word ‘Request’ in front of the instruction to place in the correct context from a conversation standpoint when communicating with ATC. ‘Request’ may be necessary for future communication, but it was not found to be helpful in this research. Many pilots were looking for the verbatim UM in the corresponding categories when creating each segment of the concatenated DM. Pilots were not concerned about the correct context of the DMs when correcting variables within the clearance. It was understood that the message was being sent to ATC, and that pilots were technically requesting a clearance without actually stating the word ‘Request’. Of the sixteen UMIs that were used in this study, seven DMs were fictitiously created in order to supply the pilot with a valid option to respond to ATC’s request when the clearance was rejected. There were no DMs available in the current SC-214 document that were adequate as a response to seven different UMIs. Research needs to be conducted either testing new DMs in response to complex UMIs, or testing current DMs in response to complex UMIs.

Simulation research that includes realistic flight tasks along with communication using DataComm should be conducted under high stress high WL conditions. There are hundreds of UMIs and DMs contained within the RTCA SC-214 Message Set and many combinations of 4DT complex clearances could be developed and tested on the current dynamic flight simulator used for this study. There is a need for research that considers how DMs will be combined given the sheer number
of DMs, along with the potential combinations, to support the language of conversations between ATC and pilots. There is a need to determine how this language may change given it is not voice and also that it must depict more information within a single clearance.

Graphical representations illustrating the reason for ATC clearances could be provided to the pilot to support pilots’ reasoning when accepting or rejecting a clearance. Pilots stated that their tolerance level for accepting a clearance would be different depending on the reason for the clearance. In this study, a reason such as weather or traffic was displayed as text for a route clearance or altitude change, (written above the clearance itself), but these reasons were not graphical depicted on the ND. If all the information were made available, pilot decision making could be enhanced. Pilots would also have a clear obstacle to maneuver through or around when creating a DM (versus just bringing the route back onto the original flight path as instructed for this study). Complex 4DT clearances could be tested under a simulated environment.

4DT trajectories need further evaluation with the current CDU to see how difficult complex route clearances would be for pilots to negotiate and input into the DataComm system during flight. This research could potentially highlight the shortcomings of the current CDU and interface capabilities that would be necessary for near term DataComm implementation.

Voice activated commands to create DMs or to activate menu systems within a specific communication interface could also be evaluated. Voice activation is not widely considered within the aviation community for flight deck implementation on
commercial airliners because of external noise. However, newer systems with noise cancellation and other advances in the technology may be possible in the future. Depending on the error rates, such a system could reduce physical and cognitive WL along with pilot input error.

Evaluation of alternate graphics to depict temporal data should be tested. This research stated the specific Zulu time next to the position where the pilot should either initiate a section of a clearance, or the position that the plane must occupy at the specific Zulu time (depending on the clearance). The times depicted on the ND always directly corresponded with the time stated in the clearance. When the clearance was meant to be accepted, then pilots thought the time next to the position was helpful, but when the route clearance correctly brought the pilot back onto the flight path, and the time was incorrect, pilots often did not catch this error. Alternate graphics need to be tested that clearly depict a direct comparison between the time within the clearance, and the current Zulu time, representing the feasibility of the suggested time.

Many alternative graphics, (besides the ones used in this research), could be tested for route, altitude, speed, and heading clearances. There are many options and graphics available to depict these. The conventional dashed lines for route alterations and carets for heading were understood by all pilots tested in this research (even though many pilots stated that the concatenated clearances used in the scenarios were not common under current operations). The graphics directly matched the text clearance from a cognitive standpoint. However, although not common today, if ATC instructed a plane to fly a specific heading, and then provided
a ‘proceed direct’ UM directly after, then the heading essentially becomes a segment of a route clearance. The heading itself then could be depicted with just a dashed line since it reconnects with another route instruction. Alterations of these graphics could be tested. An example where this sequence of UMs might be applicable is if ATC wanted a plane to fly to specific latitude, longitude where a VOR station or waypoint is not currently located. ATC could use a heading to accomplish this instruction ending at the desired location to avoid traffic or a weather cell, and then utilize the pilot preferred ‘Proceed Direct’ route instruction to bring the plane back on the original flight path.

10.0 Conclusion

Two separate DM creation interfaces were developed for this thesis (TextGen and AutoGen). Both presentation formats had the ability to communicate with a simulated ATC station while also depicting clearances via text and graphics on a standard ND. Results indicated that pilots unanimously preferred UM graphics to clearly convey the clearance instruction, especially once clearances became increasingly challenging. Similarly, pilots also unanimously preferred DM graphics to clearly convey the messages that were being created to communicate with ATC. Direct graphical manipulation (AutoGen) was preferred by all pilots in comparison to the menu-based system (TextGen). Automation features implemented in AutoGen are not anticipated to be implemented near-term within NextGen technologies, but future research to further expand upon its functionalities and integration is critical for DataComm research. DataComm systems will need
continued improvement as clearance length and complexity increase to meet future demand within the NAS.
APPENDIX A

Experiment I Participant Instructions

The purpose of this study is to evaluate ways to create down-link messages when you have received an unacceptable up-link clearance during flight. During this experiment an initial clearance displayed as text and graphics on a touchscreen monitor will appear. You will have the option to either accept or reject this clearance by responding with a “WILCO”, or “UNABLE” as shown in the figure below. If you “WILCO” the clearance, then the clearance will disappear, and a second clearance, un-related to the first, will pop up on the navigation display. If you click “UNABLE” for any clearance, then you will be required to create a downlink message related to the clearance you rejected using a set of specific rules that will be outlined later in this document.
If you select “UNABLE”, six categories for creating downlink messages (DMs) will pop up on the screen to allow you to respond to the original clearance. You will be required to concatenate these DMs together to construct a downlink message (DM) to send to the simulated Air Traffic Control (ATC) station. This process is depicted in the figure below. The Route tab is selected and the DM “AT [Position] REQUEST DIRECT TO [Position]” is selected.
Downlink Message creation with Variable Input (Touchscreen Monitor)
The only buttons that you will be interacting with during the simulation on the X-Plane touchscreen are highlighted in blue in Figure 3. The buttons on the right side are to de-clutter the navigation display (Removing airports, VOR stations, NDBs, Waypoint symbols, etc.). The left side of the highlighted blue box contains a knob to manipulate the range on the navigation display. The discrete range options are 10, 20, 40, 80, 160, 320, and 640 nautical miles. Both navigation displays, (on the X-Plane monitor, and the other touchscreen), are synced. In other words, when the zoom or de-clutter options are interacted with on the X-Plane side, then these changes will also be implemented on the navigation display on the second touchscreen.
The zoom knob is an expanded view from the highlighted blue section in Figure 3. This knob can be difficult to interact with, but the goal is to aim for 9:00 & 3:00 when trying to increase or decrease the nautical range on the navigation displays. (10, 20, 40, 80, 160, 320 Nautical Mile Ranges). A small capacitive stylus will be provided if the pilot desires to utilize for more precise interaction with each touchscreen.
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DM #</th>
<th>DESCRIPTION OF MESSAGE</th>
<th>DOWN-LINK MESSAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALTITUDE</td>
<td>6</td>
<td>Request for the specified level or vertical range.</td>
<td>REQUEST [level]</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>11</td>
<td>Request for a climb/descent to the specified level or vertical range to commence at the specified position.</td>
<td>AT [position] REQUEST [level]</td>
</tr>
<tr>
<td>ALTITUDE</td>
<td>78</td>
<td>Request direct to a specific position once reaching a specific altitude.</td>
<td>AT LEVEL [level] PROCEED DIRECT TO [Position]</td>
</tr>
<tr>
<td>TIME</td>
<td>13</td>
<td>Request for a climb/descent to the specified level or vertical range to commence at the specified time.</td>
<td>AT TIME [time] REQUEST [level]</td>
</tr>
<tr>
<td>TIME</td>
<td>76</td>
<td>Request direct to a specific position at a specific time.</td>
<td>AT TIME [time] PROCEED DIRECT TO [Position]</td>
</tr>
<tr>
<td>OFFSET</td>
<td>15</td>
<td>Request for a parallel track from the cleared route by the specified distance in the specified direction.</td>
<td>REQUEST OFFSET [specified distance] [direction] OF ROUTE</td>
</tr>
<tr>
<td>OFFSET</td>
<td></td>
<td>Request for a parallel track from the cleared route by the specified distance in the specified direction starting at a specific position.</td>
<td>AT [Position] REQUEST OFFSET [specified distance] [direction] OF ROUTE</td>
</tr>
<tr>
<td>HEADING</td>
<td>70</td>
<td>Request for the specified heading.</td>
<td>REQUEST HEADING [degrees]</td>
</tr>
<tr>
<td>HEADING</td>
<td>97</td>
<td>Request a specified heading at a specific position.</td>
<td>AT [Position] FLY HEADING [Degrees].</td>
</tr>
<tr>
<td>ROUTE</td>
<td>22</td>
<td>Request for a direct clearance to the specified position.</td>
<td>REQUEST DIRECT TO [Position]</td>
</tr>
<tr>
<td>ROUTE</td>
<td>119</td>
<td>Request that when the first specified position is reached direct clearance to the second specified position is issued.</td>
<td>AT [position] REQUEST DIRECT TO [Position]</td>
</tr>
</tbody>
</table>
Reasons to “Reject” an incoming clearance:

1. **(Position)** If the clearance does not bring you back onto your original route, then you must reject it. (Note: This only applies to scenarios where you are taken off your route.) Offsets should be rejected if the number of nautical miles taken off your original route is more than 30 nautical miles.

2. **(Altitude)** You must reject clearances that require you to climb to an altitude that you are already above. Similarly, you must reject clearances that require you to descend to an altitude that you are already below. Note: If there is a route change along with the altitude change in a specific scenario, then the route must be created exactly the same way in the downlink clearance when sending to ATC. (*The only thing that you need to do is simply correct the “climb to”, or “descend”. The numbers for the altitudes should be the same. If you enter an incorrect number, then that is an error.*)

3. **(Heading)** If the heading symbol at the end of a clearance does not eventually intersect the original flight plan, then you need to “reject” those clearances. (*Each clearance from ATC must complete the path*
back to the original flight path regardless of clearance type for the entire experiment.) In other words, if there was a heading, or vector, that leads you in a direction that does not bring you back on the original flight path, then this specific clearance must be rejected.

4. **[Time]** If the clearance requires you to either re-route the plane, or change your altitude at a specific time, and the time is not accurate, then you must reject that clearance, and simply state a time that makes sense based on current speed and time.

5. **[Speed]** Clearances with speed involved that would not be acceptable based on your altitude or position on the route should be rejected. Speeds that would be too slow based on the position of your flight should also be rejected.
Reasons to “Accept” an incoming clearance:

1. **(Position)** If the clearance provides a route change, but successfully brings the plane back onto the original flight path, then this would be an example of an “Accept”. Examples of the plane coming back onto their route would include a heading that intersects their original flight plan, as well as “Proceed direct via position” that brings the plane back onto their original route. Offsets should be accepted if the number of nautical miles taken off their original route is less than 30 nautical miles.

2. **(Altitude)** If the altitudes seem correct given your current altitude, then you should accept this clearance.

3. **(Heading)** If a specific heading intersects your original flight path, then you should accept this type of clearance.

4. **(Time)** If the time in the Uplink clearance seems acceptable given the current speed and time, (within reason), then this type of clearance should be accepted.

5. **(Speed)** Clearances with speed involved that would be acceptable based on your position in flight, and given the type of plane that you are flying, should be accepted.
Rules and objectives for pilots when placed in the simulator:

1. Your goal is to create a message that gets you back onto your flight path.
   ✓ If an incoming ATC message takes the plane way off your original flight path, then you are required to create a Downlink message that brings the plane back onto the original flight plan.

2. You will be required to create the same message structure that was originally sent to you. For instance:
   ✓ If an “Offset” was sent for traffic in the Uplink clearance, then an “Offset” needs to be created in the reply.
   ✓ Whenever a “proceed direct” clearance has been sent in the Uplink clearance, then a “Proceed Direct” needs to be created for the downlink message.
   ✓ If a “heading” was presented to you in the Uplink Clearance, then a “heading” clearance needs to be created as a downlink message.
   ✓ Whenever an altitude is listed in the Uplink Clearance, (And that part of the clearance is considered acceptable), then you need to input a message with that exact altitude in the downlink message with the corrected re-routing.
   ✓ If the altitude is considered “Unacceptable”, then you need to input an altitude that is considered acceptable (within reason).

3. Whenever there is an “Offset” created on the DM side, (In addition to the rule stated in #2), the pilot must immediately follow that message with a “Rejoin Route before passing position” just like it is stated in the uplink clearance.

4. When selecting positions as input variables to the down-link messages, only **waypoints** should be selected. Waypoints are indicated by the triangle symbols on both navigation displays.
General Notes to keep in mind:

1. There are no differences between the text clearance and the graphics depicted on the navigation display. In other words, whatever positions are referenced in the text clearance section with respect to altering the flight path, the navigation display will depict the exact path. Only the route of the path itself needs to be examined. Even if the name of a position cannot be seen on the navigation display because of a specified zoom level, it is still the point being referenced in the clearance section.

2. Disregard rejecting clearances for the following reasons:
   - Limitations of the capability of the aircraft
   - Passenger discomfort
   - Fuel Economy (During descents)

3. Ignore purple track bug on the navigation displays. It is irrelevant to the study.

The experimenter cannot clarify any of the text messages or map displays during the experimental trials. If you have a concern or comment about a particular trial, enter your response and THEN ask the experiment to note the trial number and your concern before the next trial. You will be given a break half way through the experiment (after 10 trials). However, if you feel the need for a break before then, or at any time, just let the experimenter know.

Do you have any questions?

We will now start a practice trial for you to get familiar with the procedure
   - Feel free to ask any questions during these practice trials.

Now we will begin the experiment.
## APPENDIX B

### Experiment I - 20 Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Clearance 1</th>
<th>Clearance 2</th>
<th>Clearance 3</th>
<th>Clearance 4</th>
<th>Clearance 5</th>
<th>Clearance 6</th>
<th>Clearance 7</th>
<th>Clearance 8</th>
<th>Clearance 9</th>
<th>Clearance 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>UM27, UM339</td>
<td>UM23, UM77</td>
<td>UM25, UM78</td>
<td>UM23, UM77, UM97</td>
<td>UM76, UM339</td>
<td>UM64, UM68</td>
<td>UM28, UM76</td>
<td>UM65, UM68</td>
<td>UM188, UM97</td>
<td>UM46, UM310</td>
</tr>
</tbody>
</table>

**Scenario 1**
- **Clearance 1**: UM27, UM339  
  - CLIMB TO REACH [level] BEFORE PASSING [position]. AT [position] CLEARED TO [position] VIA [route clearance].
- **Clearance 2**: UM23, UM77  
  - DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position].

**Scenario 2**
- **Clearance 3**: UM25, UM78  
  - AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position].
- **Clearance 4**: UM23, UM77, UM97  
  - DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].

**Scenario 3**
- **Clearance 5**: UM76, UM339  
- **Clearance 6**: UM64, UM68  
  - OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position].

**Scenario 4**
- **Clearance 7**: UM28, UM76  
  - DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position].
- **Clearance 8**: UM65, UM68  
  - AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position].

**Scenario 5**
- **Clearance 9**: UM188, UM97  
- **Clearance 10**: UM46, UM310  
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance 12</td>
<td>UM23, UM77</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position].</td>
<td></td>
</tr>
<tr>
<td>Scenario 7</td>
<td>Clearance 13</td>
<td>UM25, UM78</td>
<td>AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]</td>
</tr>
<tr>
<td>Clearance 14</td>
<td>UM23, UM77, UM97</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].</td>
<td></td>
</tr>
<tr>
<td>Scenario 8</td>
<td>Clearance 15</td>
<td>UM76, UM339</td>
<td>AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td>Clearance 16</td>
<td>UM64, UM68</td>
<td>OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
<td></td>
</tr>
<tr>
<td>Scenario 9</td>
<td>Clearance 17</td>
<td>UM28, UM76</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position].</td>
</tr>
<tr>
<td>Clearance 18</td>
<td>UM65, UM68</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
<td></td>
</tr>
<tr>
<td>Clearance 22</td>
<td>UM23, UM77</td>
<td>DESCEND TO [level]. AT [position]</td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>Clearance</td>
<td>UM</td>
<td>Text</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>----</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>12</td>
<td>23</td>
<td>UM25, UM78</td>
<td>AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>UM23, UM77, UM97</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>UM64, UM68</td>
<td>OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td>14</td>
<td>27</td>
<td>UM28, UM76</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position].</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>UM65, UM68</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>UM46, UM310</td>
<td>CROSS [position] AT LEVEL [level]. AT LEVEL [level single] MAINTAIN [speed]</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>UM23, UM77</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position].</td>
</tr>
<tr>
<td>17</td>
<td>33</td>
<td>UM25, UM78</td>
<td>AFTER PASSING [position] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]</td>
</tr>
<tr>
<td>Scenario</td>
<td>Clearance</td>
<td>Aircraft</td>
<td>Instruction</td>
</tr>
<tr>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>18</td>
<td>34</td>
<td>UM23,UM77, UM97</td>
<td>DESCEND TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees].</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>UM76, UM339</td>
<td>AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>UM64, UM68</td>
<td>OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
<tr>
<td>19</td>
<td>37</td>
<td>UM28, UM76</td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position].</td>
</tr>
<tr>
<td></td>
<td>38</td>
<td>UM65, UM68</td>
<td>AT [position] OFFSET [specified distance] [direction] OF ROUTE. REJOIN ROUTE BEFORE PASSING [position]</td>
</tr>
</tbody>
</table>
APPENDIX C

Experiment I Flights

20 US Flights Created for 20 Scenarios...........................................(City to City)

1. Seattle, Washington..................................to.................................Boise, Idaho
2. Missoula, Montana..................................to.................................Rapid City, South Dakota
4. Duluth, Minnesota..................................to.................................Des Moines, Iowa
5. Green Bay, Wisconsin..........................to.................................Chicago, Illinois
6. Buffalo, New York..........................to.................................Augusta, Maine
7. Richmond, Virginia..........................to.................................Columbus, Ohio
8. Boston, Massachusetts..........................to.................................Roanoke, Virginia
9. Charleston, South Carolina..........................to.................................Cincinnati, Ohio
10. Savannah, Georgia..........................to.................................Fort Lauderdale, Florida
11. Louisville, Kentucky..........................to.................................Pensacola, Florida
12. St. Louis, Missouri..........................to.................................Jackson, Mississippi
13. Kansas City, Kansas..........................to.................................Baton Rouge, Louisiana
14. Scottsbluff, Nebraska..........................to.................................Indianapolis, Indiana
15. Manhattan, Kansas..........................to.................................San Antonio, Texas
17. Las Cruces, New Mexico..........................to.................................Grand Junction, Colorado
18. Idaho Falls, Idaho..........................to.................................Nogales, Arizona
19. Ogden, Utah..........................to.................................Yuma, Arizona
20. Reno, Nevada..........................to.................................Portland, Oregon
APPENDIX D

Experiment I - Pilot Questions

1. Did you feel that the downlink interface was intuitive once you were initially trained on the objective and purpose of the experiment?
2. Were the graphics helpful when creating the downlink clearance?
3. Do you think you would be able to create just as accurate downlink message to ATC if no graphics were provided at all?
4. Once the precision, consistency, and overall fidelity increase between graphics and text to accurately depict the ‘true intent’ of the clearance, would you feel comfortable with graphical implementation of concatenated clearances in the flight deck for future data link communication between pilot and ATC?
5. Once an interface was developed, (regardless if it was a touchscreen or not), and implemented in the flight deck for future communications, then would you be willing to be trained on this new system? . . . or . . . Would you rather continue with the current ACARS system and have to manually input voice clearances into the FMS?
6. What concerns do you have when implementing newer technologies into the flight deck on this level of change?
7. Do you like the idea to have another navigation display that you can interact with to change your route while in flight? (It also could be for reasons that the ATC may not see or anticipate as soon as you can.)
8. Did the graphics on the Uplink Side help at all for conveying clearances?
9. In the future, it is anticipated that there will not only be clearances sent from ATC to the pilot via text, but that the messages will be longer and concatenated with other Uplink Messages. Will you be accepting of these clearances?
APPENDIX E

Experiment II Participant Instructions

The purpose of this study is to evaluate ways of creating downlink messages when receiving an unacceptable uplink clearance during simulated flight. In this experiment an initial clearance displayed as text and graphics on a touchscreen monitor will appear. You will have the option to either accept or reject this clearance by responding with a “WILCO”, or “UNABLE” as shown in figure 1a below. If you “WILCO” the clearance then the clearance will disappear, and a second clearance, unrelated to the first, will pop up on the navigation display. If you click “UNABLE” for any clearance, then you will be required to create a downlink message with the same structure as the uplink clearance, but with different variables.
This numbered keypad will appear when inputting any changes in altitude, time, or speed.

X-Plane Flight Simulation Software depicted on the first touchscreen monitor.

The only buttons that you will be interacting with during the simulation on the X-Plane monitor on your left are highlighted in blue in Figure 3. The buttons on the right side are to de-clutter the navigation display (Removing airports, VOR stations, NDBs, Waypoint symbols, etc.). The left side of the highlighted blue box contains a knob to manipulate the range on the navigation display. The discrete range options are 10, 20, 40, 80, 160, 320, and 640 nautical miles. Both navigation displays, (on the X-Plane monitor, and the other touchscreen), are synced. In other words, when the zoom or de-clutter options are interacted with on the X-Plane side, then these changes will also be implemented on the navigation display on the second touchscreen.
The following table shows six different types of clearances provided during the experiment:

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Clearance 1</th>
<th>UM27, UM339</th>
<th>CLIMB TO REACH [level] BEFORE PASSING [position ATW]. AT [position] CLEARED TO [position] VIA [route clearance]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance 2</td>
<td>UM20, UM77, UM97</td>
<td></td>
<td>CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>Clearance 3</td>
<td>UM76, UM339</td>
<td></td>
<td>AT TIME [time] PROCEED DIRECT TO [position]. AT [position] CLEARED TO [position] VIA [route clearance]</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Clearance 4</td>
<td>UM25, UM78, UM97</td>
<td>AFTER PASSING [position ATW] DESCEND TO [level]. AT LEVEL [level single] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
<tr>
<td>Clearance 6</td>
<td>UM28, UM76, UM97</td>
<td></td>
<td>DESCEND TO REACH [level] AT OR BEFORE TIME [time]. AT TIME [time] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
</tr>
</tbody>
</table>

The zoom knob in the above screenshot is an expanded view from the highlighted blue section in Figure 3. This knob can be difficult to interact with, but the goal is to aim for 9:00 & 3:00 when trying to increase or decrease the nautical range on the navigation displays.
Reasons to “Reject” an incoming clearance:

1. **(Position)** If the clearance does not bring you back onto your original route, then you must reject it. (Note: This only applies to scenarios where you are taken off your route.)

2. **(Altitude)** You must reject clearances that require you to climb to an altitude that you are already above. Similarly, you must reject clearances that require you to descend to an altitude that you are already below. Note: If there is a route change along with the altitude change in a specific scenario, then the route must be created exactly the same way in the downlink clearance when sending to ATC. *(The only thing that you need to do is simply correct the “climb to” or “descend”. The numbers for the altitudes should be the same. If you enter an incorrect number, then that is an error.)*

3. **(Heading)** If the heading symbol at the end of a clearance does not eventually intersect the original flight plan, then you need to “reject” those clearances. *(Each clearance from ATC must complete the path back to the original flight path regardless of clearance type for the entire experiment.)* In other words, if there was a heading, or vector, that leads you in a direction that does not bring you back on the original flight path, then this specific clearance **must be rejected**.

4. **(Time)** If the clearance requires you to either re-route the plane, or change your altitude at a specific time, and the time is not accurate, then you must reject that clearance, and simply state a time that makes sense based on current speed and time.

5. **(Speed)** Clearances with speed involved that would not be acceptable based on your altitude or position on the route should be rejected. Speeds that would be too slow based on the position of your flight should also be rejected.
Reasons to “Accept” an incoming clearance:

1. **(Position)** If the clearance provides a route change, but successfully brings the plane back onto the original flight path, then this would be an example of an “Accept”. Examples of the plane coming back onto their route would include a heading that intersects their original flight plan, as well as “Proceed direct via position” that brings the plane back onto their original route.

2. **(Altitude)** If the altitudes seem correct given your current altitude, then you should accept this clearance.

3. **(Heading)** If a specific heading intersects your original flight path, then you should accept this type of clearance.

4. **(Time)** If the time in the Uplink clearance seems acceptable given the current speed and time, then this type of clearance should be accepted.

5. **(Speed)** Clearances with speed involved that would be acceptable based on your position in flight, and given the type of plane that you are flying, should be accepted.
Rules and objectives for pilots when placed in the simulator:

1. Your goal is to create a message that gets you back onto your flight path.
   - If an incoming ATC message takes the plane way off your original flight path, then you are required to create a Downlink message that brings the plane back onto the original flight plan.

2. You will be required to create the same message structure that was originally sent to you. For instance:
   - Whenever a “proceed direct” clearance has been sent in the Uplink clearance, then a “Proceed Direct” needs to be created for the downlink message.
   - If a “heading” was presented to you in the Uplink Clearance, then a “heading” clearance needs to be created as a downlink message.
   - Whenever an altitude is listed in the Uplink Clearance, (And that part of the clearance is considered acceptable), then you need to input a message with that exact altitude in the downlink message with the corrected re-routing.
   - If the altitude is considered “Unacceptable”, then you need to input an altitude that is considered acceptable.

General Notes to keep in mind:

4. There are no differences between the text clearance and the graphics depicted on the navigation display. In other words, whatever positions are referenced in the text clearance section with respect to altering the flight path, the navigation display will depict the exact path. Only the route of the path itself needs to be examined. Even if the name of a position cannot be seen on the navigation display because of a specified zoom level, it is still the point being referenced in the clearance section.

5. Disregard rejecting clearances for the following reasons:
   - Limitations of the capability of the aircraft
   - Passenger discomfort
   - Fuel Economy (During descents)
6. Ignore purple track bug on the navigation displays. It is irrelevant to the study.

The experimenter cannot clarify any of the text messages or map displays during the experimental trials. If you have a concern or comment about a particular trial, enter your response and **THEN** ask the experiment to note the trial number and your concern before the next trial. You will be given a break half way through the experiment (after 10 trials). However, if you feel the need for a break before then, or at any time, just let the experimenter know.

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

#### Experiment 2 – 8 Scenarios

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clearance 2</td>
<td>UM20, UM77, UM97</td>
<td>CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>Clearance 5</td>
<td>UM188, UM97</td>
<td>AFTER PASSING [position] MAINTAIN [speed]. AT [position] FLY HEADING [degrees].</td>
<td>Accept</td>
</tr>
<tr>
<td>Clearance</td>
<td>UM Codes</td>
<td>Instructions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>----------</td>
<td>--------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>UM20, UM77, UM97</td>
<td>CLIMB TO [level]. AT [position] PROCEED DIRECT TO [position]. AT [position] FLY HEADING [degrees]</td>
<td>Reject</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>---------------</td>
<td>------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td>Clearance 17</td>
<td>UM188, UM97</td>
<td>AFTER PASSING [position] MAINTAIN [speed]. AT [position] FLY HEADING [degrees].</td>
<td>Reject</td>
</tr>
</tbody>
</table>
Experiment II Flights

8 US Flights Created for the 8 Scenarios...........................(City to City)

1. Seattle, Washington..............................to..............................Boise, Idaho
2. Idaho Falls, Idaho..................................to..............................Nogales, Arizona
4. Duluth, Minnesota...............................to..............................Des Moines, Iowa
5. Louisville, Kentucky..............................to..............................Pensacola, Florida
6. Buffalo, New York...............................to..............................Augusta, Maine
7. Richmond, Virginia..............................to..............................Columbus, Ohio
8. Boston, Massachusetts............................to..............................Roanoke, Virginia
APPENDIX H

Experiment II - Pilot Questions

1. Did you feel that the downlink interface was intuitive once you were initially trained on the objective and purpose of the experiment? **AutoGen** Yes No .......... **TextGen** Yes No

2. Were the graphics helpful when creating the downlink clearance? **AutoGen** Yes No .......... **TextGen** Yes No

3. Do you think you would be able to create just as accurate downlink clearance to ATC if no graphics were provided at all? **AutoGen** Yes No .......... **TextGen** Yes No

4. Once the precision, consistency, and overall fidelity increase between graphics and text to accurately depict the ‘true intent’ of the clearance, would you feel comfortable with graphical implementation of concatenated clearances in the flight deck for future Data Comm between pilot and ATC? Yes No

5. Once an interface was developed, (regardless if it was a touchscreen or not), and implemented in the flight deck for future communications, then would you be willing to be trained on this new system? . . . or . . . Would you rather continue with the current ACARS system and have to manually input voice clearances into the FMS?

6. What concerns do you have when implementing newer technologies into the flight deck on this level of change?

7. Do you like the idea to have another navigation display that you can interact with to change your route while in flight? (Basically for reasons that the ATC may not see or anticipate as soon as you can.)

8. Did the graphics on the Uplink Side help at all for conveying clearances?
9. In the future, it is anticipated that there will not only be clearances sent from ATC to the pilot via text, but that the messages will be longer and concatenated with other Uplink Messages. Will you be accepting of these clearances?

10. Which method did you prefer more when creating the concatenated downlink messages to ATC?
APPENDIX I

Graphics / Text Depiction

Altitude:

Time:
Offset:

OFFSET 40NM LEFT OF ROUTE
REJOIN ROUTE BEFORE PASSING EBOVE

Speed:

AFTER PASSING UJJAZ MAINTAIN 465 knots
▲ AT UJJAZ FLY HEADING 195
Route:

Heading:

Heading is depicted with carets and text shown above circled in blue
APPENDIX J

Categorical Downlink Messages

Altitude Tab:

<table>
<thead>
<tr>
<th>ALTITUDE</th>
<th>1 REQUEST [Level]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME</td>
<td>2 AT [Position] REQUEST [Level]</td>
</tr>
</tbody>
</table>

Time Tab:

<table>
<thead>
<tr>
<th>ALTITUDE</th>
<th>1 AT TIME [Time] REQUEST [Level]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME</td>
<td>2 AT TIME [Time] REQUEST DIRECT TO [Position]</td>
</tr>
</tbody>
</table>


Offset Tab:

1. REQUEST OFFSET [Specified Distance] [Direction] OF ROUTE
2. AT [Position] REQUEST OFFSET [Specified Distance] [Direction] OF ROUTE

Speed Tab:

1. REQUEST [Speed]
2. AT [Position] REQUEST [Speed]
3. AT LEVEL [Level] MAINTAIN SPEED [Speed]

Route Tab:

1. REQUEST DIRECT TO [Position]
2. AT [Position] REQUEST DIRECT TO [Position]
3. DIVERTING TO [Position] VIA [Route Clearance]
4. AT LEVEL [Level] REQUEST DIRECT TO [Position]
5. REQUEST REJOIN ROUTE BEFORE PASSING [Position]
### Heading Tab:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong></td>
<td>REQUEST HEADING [Degrees]</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>AT [Position] FLY HEADING [Degrees]</td>
</tr>
</tbody>
</table>
APPENDIX K

Simulator Overview

The simulator's Overview (purpose), capabilities, and limitations will be discussed in the following section.

Picture of Dynamic Flight Simulator used for Thesis
Simulator Overview

The overall purpose of the simulator is to provide clearances during genuine flights across the United States to cognitively test pilots’ ability to first understand the uplinked messages (UMs), and then evaluate and make a decision to either accept or reject (Wilco/Unable) the clearance based on their real time changing situation and variables. (Examples of changing variables in the clearances: Speed, Altitude, Heading, Time, and route) See Figure x below depicting a clearance with green text and green graphics.

![Screenshot depicting two options for subjects to either select Wilco or Unable](image-url)
Pilots that participated in the study were trained on what was considered acceptable and unacceptable based on the reasons and purpose of the experiment. (These rules are defined in the participant’s instructions located in Appendix A & E). Pilots during the simulation also were able to create their own DMs from a category selection process to fill in the appropriate variables. (Note: Pilots will only create DMs to ATC during situations where the initial clearance was rejected.)

**Simulator Capabilities**

- The simulator needed to create a reasonable feel and look of a real cockpit to provide an appropriate amount of situation awareness
- The simulator had to have an actual flight simulation software (X-Plane) running in the background for more realistic flight conditions.
- The simulator needed to have the ability to generate and graphically display clearances created from an adjacent computer system which acted as the simulated ATC station.
- The simulator displayed two touchscreen monitors which were integrated with X-Plane and were directly synced with each other and the adjacent ATC station. The left touchscreen displays all the controls related to X-Plane including the Primary Flight Display (PFD), the navigation display (ND), and Control Display Unit (CDU). The right touchscreen serves as the primary interface for incoming clearances from the ATC station. The text clearance appears on the rights side of the screen, and a secondary navigation display (also on the right touchscreen) displays the flight plan along with the graphics of what the clearances specifically states.
The simulator needed to operate both Pilot/ATC interfaces (TextGen / AutoGen) created for the experiments. These interfaces provided a platform to communicate with ATC to send concatenated downlink messages with graphical representation.

The simulator needed to have the capability to capture and record the required data for the experiments including: Response times to answer clearance, time to create a concatenated downlink message, and the actual message that the pilots created. The system also records the pilot’s response, what the correct answer was, and whether or not they were correct. Their age, gender, flight hours experience, pilot rating, and whether or not they were instrument rated were also recorded.

The ATC station literally contains every message within the SC-214 message set, and can send them across the system to test pilots’ cognitive ability on how they translate during an authentic flight simulation during different situations.

**Simulator Limitations**

The simulator cannot actually load a clearance into the FMS once accepted by a pilot. In other words, the avionics system is not directly linked with the ATC station or the CDU depicted within the cockpit. Once a pilot accepts a clearance the information from ATC clears, and a new clearance, irrelevant to the previous, appears on the screen.

The simulator does not graphical depict the reason for the clearance. Both ATC communication interfaces do state the reason for the clearance (either
traffic or weather), but they do not graphically depict the weather cells or other nearby planes on the navigation display. This would have helped tremendously to alleviate confusion for the reasons to reject specific situations for the pilots.

- The simulator does not allow the test subjects to communicate with ATC as they are able to in the real world today. They often desired this capability when a confusing and complicated clearance appeared on the screen. Pilots were only able to communicate via text messages.

- The simulator does not provide any moving hydraulic parts to simulate vibrations and authentic turbulence.
REFERENCES


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