# TECHNICAL REPORT DOCUMENTATION PAGE

| 1. REPORT NO. | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO. |
|---|---|---|
| 4. TITLE AND SUBTITLE<br>DataComm – Display Alternatives for the Flight Deck: Overview and Human Factors Recommendations<br>Volume 1 | | 5. REPORT DATE<br>February 28, 2013<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Gallimore, J.J., Shingledecker, C., and Tsang, P.S. | | 8. PERFORMING ORGANIZATION REPORT<br>Click here to enter text. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Wright State University<br>3640 Colonel Glenn Hwy<br>Dayton, OH 45305 | | 10. WORK UNIT NO.<br>11. CONTRACT OR GRANT NO.<br>DTFAWA-10-A-80021 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>Federal Aviation Administration<br>Office of NextGen<br>Human Factors Division<br>800 Independence Ave, SW<br>Washington, DC 20591 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final Report<br>14. SPONSORING AGENCY CODE<br>ANG-C1 |

15. SUPPLEMENTARY NOTES

FAA Technical Point of Contact: Daniel A. Herschler, 202-267-9853

16. ABSTRACT

As DataComm is a key enabling technology that significantly affects human performance, human factors experts have anticipated potential implementation challenges (Cardosi, Lennertz and Donahoe (2010). One significant issue is that DataComm equipment may not be integrated with flight management systems (FMS). The crew will be required to read the DataComm messages, interpret them, make decisions with respect to the flight, and then make the appropriate FMS input. There will be challenges for the flight crew even when DataComm and FMS flight deck systems are fully integrated. For example, in Trajectory Based Operations (TBO), textual clearance displays that provide complex 4D trajectory information may be difficult for pilots to interpret in a timely and efficient manner without error. Current aircraft systems that have incorporated datalink to some extent have utilized text to provide clearances or messages from ATC to the pilot. Presenting spatial information to pilots via text only requires pilots to perform a mental transformation that can not only slow down the understanding of the messages, but also lead to interpretation errors. Thus, this research addressing presentation methods of ATC information received on the flight deck via DataComm is high priority. The development of human factors recommendations to support human factors specialists in the FAA Aircraft Certification Service and Flight Standards Services is one of the major contributions of this research (Appendix 1).

After a review of the existing literature on the subject, a series of human-in-the-loop (HITL) experiments were conducted to evaluate pilot performance using text clearances and hybrid graphic and text clearances for uplink messages (UMs) to the flight deck and downlink messages (DMs) to ATC. The results of the studies conducted are provided in Vol 2 of this final report. That volume provides the details of the methods, results and discussion of each study.

| 17. KEY WORDS | 18. DISTRIBUTION STATEMENT | | |
|---|---|---|---|
| data communications; controller-pilot datalink communications; operating limitations; flight deck procedures; flight management system | Distribution unlimited | | |
| 19. SECURITY CLASSIF. (OF THIS REPORT)<br>Unclassified | 20. SECURITY CLASSIF. (OF THIS PAGE)<br>Unclassified | 21. NO. OF PAGES<br>91 | 22. PRICE<br>N/A |

**Form DOT F 1700.7 (08/72)**

# DataComm – Display Alternatives for the Flight Deck: Overview and Human Factors Recommendations Volume 1

**Cooperative agreement DTFAWA-10-A-80021**

**February 28, 2013**

**Prepared For FAA, NextGen Advanced Concepts and Technology Development, Human Factors Division (ANG-C1)**

**Prepared by:**

**Wright State University**

**3640 Colonel Glenn Hwy**

**Dayton, OH 45305**

WRIGHT STATE UNIVERSITY

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

**Research Team**

| **Team Member** | **Role** |
|---|---|
| Jennie J. Gallimore, Ph.D. | Principle Investigator |
| Clark Shingledecker, Ph.D. | Co-Investigator |
| Pamela S. Tsang, Ph.D. | Co-Investigator |
| **Staff** | |
| Blake Ward | Lead Programmer |
| Randall Green | Programmer |
| **Students** | |
| Steven 'Brent' Kiss | M.S. Human Factors Engineering Graduate Student |
| Ricardo 'Danny' Munoz | M.S. Human Factors Engineering Graduate Student |
| Chang-Geun Oh | Ph.D. Engineering Graduate Student |
| Timothy Crory | Ph.D. Psychology Graduate Student, Pilot |
| Mark Geise | Programmer, Lead Programmer |

**Acknowledgements**

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 during review of the human factors recommendations.

## ACRONYMS

| | |
|---|---|
| 3D | Three Dimensional |
| 4D | Four Dimensional |
| 4DT | Four-dimensional Trajectory |
| AC | Advisory Circular |
| ANSI | American National Standards Institute |
| ASD | Altitude Situation Display |
| ATC | Air Traffic Control |
| DataComm | Data Communications |
| DC-MAT | DataComm Message Assessment Tool |
| DM | Downlink Message |
| EFB | Electronic Flight Bag |
| ETE | Estimated Time Enroute |
| ETA | Estimated Time of Arrival |
| FAA | Federal Aviation Administration |
| FANS | Future Air Navigation System |
| FL | Flight Level |
| FMS | Flight Management System |
| FOR | Frame Of Reference |
| GPS | Global Positioning System |
| GraphicGen | Graphic Generator |
| HF | Human Factors |
| HFES | Human Factors and Ergonomics Society |
| HFS | Human Factors Standards |
| HITL | Human In The Loop |
| ISAP | International Symposium on Aviation Psychology |
| MCDU | Multi-function Control Display Unit |
| MSG | Message |
| NAS | National Airspace System |
| NASA | National Aeronautics and Space Administration |
| ND | Navigation Display |
| NDB | Non-Directional Beacon |
| NextGen | Next Generation Air Transportation System |
| NRS | Navigation Reference System |
| RTA | Required Time of Arrival |
| RTCA | Radio Technical Commission for Aeronautics |
| SC-214 | Special Committee 214 |
| SD | Standard Deviation |
| SME | Subject Matter Expert |
| TBO | Trajectory-Based Operations |
| TextGen | Text Generator |
| UM | Uplink Message |
| VOR | Very high frequency Omnidirectional Range |
| WILCO | Will Comply |
| WG-78 | Working Group 78 |

# 1. Executive Summary

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

DataComm will provide the following benefits:

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

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

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

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

Supporting the FAA's Aircraft Certification Service need for regulatory guidance to evaluate alternative flight deck displays, research was conducted to develop human factors recommendations for such regulatory guidance concerning the minimum requirements for system characteristics and display of air traffic trajectory clearances on the flight deck. After a review of the existing literature on the subject, a series of human-in-the-loop (HITL) experiments were designed and conducted to evaluate human performance using text clearances and hybrid graphic and text clearances for uplink messages (UMs) to the flight deck and downlink messages (DMs) from the flight deck to ATC. Three experiments were conducted using different experimental paradigms. While it seems reasonable that graphics would provide pilots with information in a spatial format and would be easier to understand than text, a text condition was included in our studies to provide a baseline for comparison of the performance effects of graphics or hybrids of graphics and text as compared to text alone.

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

The results of the studies conducted are provided in Vol 2 of this final report. That volume provides the details of the methods, results and discussion of each study.

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

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

## Table of Contents

## List of Figures

# 2. Introduction

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

DataComm will provide the following benefits:

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

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

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

To address this challenge, alternative flight deck displays with graphics, hybrid text and graphics, and other formats integrated with existing navigation displays or new DataComm displays may enable pilots to more easily identify, understand, and quickly respond to air traffic clearances and instructions. Alternative displays may also better support negotiation of clearances. The research was conducted to support the FAA's Aircraft Certification Service need for regulatory guidance to evaluate alternative flight deck displays.

## 2.1. Objective

The primary objective of this project was to research and develop human factors recommendations that provide the minimum interface requirements necessary for depicting graphical clearance data in operations involving DataComm. The purpose of these recommendations are to support human factors specialists in the FAA Aircraft Certification Service and Flight Standards Service to evaluate the acceptability of text and graphical flight deck display formats and associated flight crew procedures for simple and complex DataComm messages that will be used in the NextGen context.

Primary Tasks

The research approach included completion of the following primary tasks:

1) Review literature for existing design guidance that may be appropriate for flight deck DataComm displays.
2) Develop graphical and symbolic display and input alternatives for flight deck display of routes and novel (Non-traditional) display of ATC clearances and instructions. Perform human-in-the-loop part task studies to evaluate human performance and flight crew responses.
3) Develop information and human factors requirements that support minimum interface requirements for depicting graphical clearance data; and develop evaluation concepts and tools that could be used by FAA certification personnel to determine whether flight deck displays meet minimum human factors requirements.

## 2.2. Research Assumptions

There are a large number of variables that can affect pilot performance using DataComm. To complete this research, assumptions were made about the state of development of the NextGen system:

1. Mixed aircraft datalink equipage.
2. Some upgraded technology and use of ground technology.
3. Integrated DataComm messages can be provided in MCDU for review and then directly loaded into FMS. (Loading to FMS was not evaluated).
4. Ability to assess trial flight plans.
5. Ground automation elements will have ability to coordinate trajectories, set time constraints over a single waypoint.
6. Departure and approach optimization tools will feed the trajectory formulation process.

## 2.3. Research Scope and Caveats

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

In addition to evaluating text and hybrid formats an additional factor was the number of elements in a UM or DM. The term “element” is used to define the variable that is being specified by the UM or DM. For example the UM “At [LEVEL] proceed direct to [POSITION] is one UM with two elements. A clearance is composed of one UM or a concatenation of UMs with one or more elements. A DM is composed of one DM or a concatenation of DMs with one or more elements.

Generally, as the number of elements increase an increase in response time is expected; however, the complexity level related to different UMs, DMs or their concatenations cannot be calibrated with precision. The inclusion of number of elements (through concatenation) does provide trend information with respect to the difficulty and time needed to interpret clearances and messages.

Another consideration is the creation of flight scenarios. The scenarios influence performance. Many different scenarios were created, and as lessons were learned with respect to unrealistic scenarios, they were be deleted from the research. However, this research did not explicitly control for scenarios. Each UM and DM is unique and how they might be concatenated is also unique. In order to use UMs or DMs they must be placed within a likely scenario.

We did not collect data to evaluate specific UMs or DMs or their concatenation with respect to human performance. However, participant pilots provided feedback in this area and the information is provided in Appendix 3.

## 2.4. Human-in-the-Loop Simulation Methods

The research used part-task human-in-the-loop (HITL) simulation. Two different simulation techniques were utilized: 1) a static display of information via an evaluation tool called Data Communications Message Assessment Tool (DC-MAT) and 2) the use of dynamic display of information within a flight simulation. The specific data values of time to respond and errors are therefore under conditions where one pilot is focusing their attention on DataComm.

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

## 2.5. Report Layout

The Final Report is divided into two Volumes. Volume 1 provides a brief introduction, objectives, and briefly presents information about the displays and methods used. Three Appendices are included: Appendix 1 is the specific human factors recommendations for FAA certification personnel. Appendix 2 describes the DC-MAT, a tool that can be used by the FAA certification personnel to determine whether flight deck displays meet minimum human factors requirements. Appendix 3 provides pilot feedback related to UMs, DMs and their concatenation that may be useful input to the SC-214 message set.

The purpose of Volume 2 is to provide a more in-depth understanding of the three specific research studies conducted.

### 2.6. Human-in-the-Loop Simulation Methods

#### 2.6.1. Method 1: Static Display of Text and Graphic UMs

A methodology was created to rapidly evaluate new and modified DataComm cockpit displays using a variety of complex data communications, including the use of concatenated messages. The test method uses a binary judgment task to collect performance data on clearance interpretation time and errors, and to obtain feedback from pilots concerning the interpretability of clearances. The method currently focuses on UM clearances from ATC to the flight deck that affect an aircraft's current or future trajectory (e.g. speed, heading, altitude, route, clearances and restrictions). Note that this methodology is not designed to evaluate UMs or instructions that do not affect the route of flight, e.g. transfer of communications, contact/monitor, or report requests.

On each test trial, pilot participants were presented with a flight plan and scenario, which situated them at a position on the route. They were then asked to judge the acceptability of an ATC clearance presented on a visual display (text or hybrid presentation of UMs) in the context of the plan and their current position, and phase of flight. The speed and accuracy of the pilot's binary judgment (accept/reject) responses to these clearances were used to assess the ease with which the participants were able to interpret the clearance. Pilots can provide verbal feedback related to the scenario and UM after completing the judgment. Figure 1 illustrates the format of the DC-MAT tool. Appendix 2 provides a more in-depth description of the DC-MAT including rationale, uses, and future work.

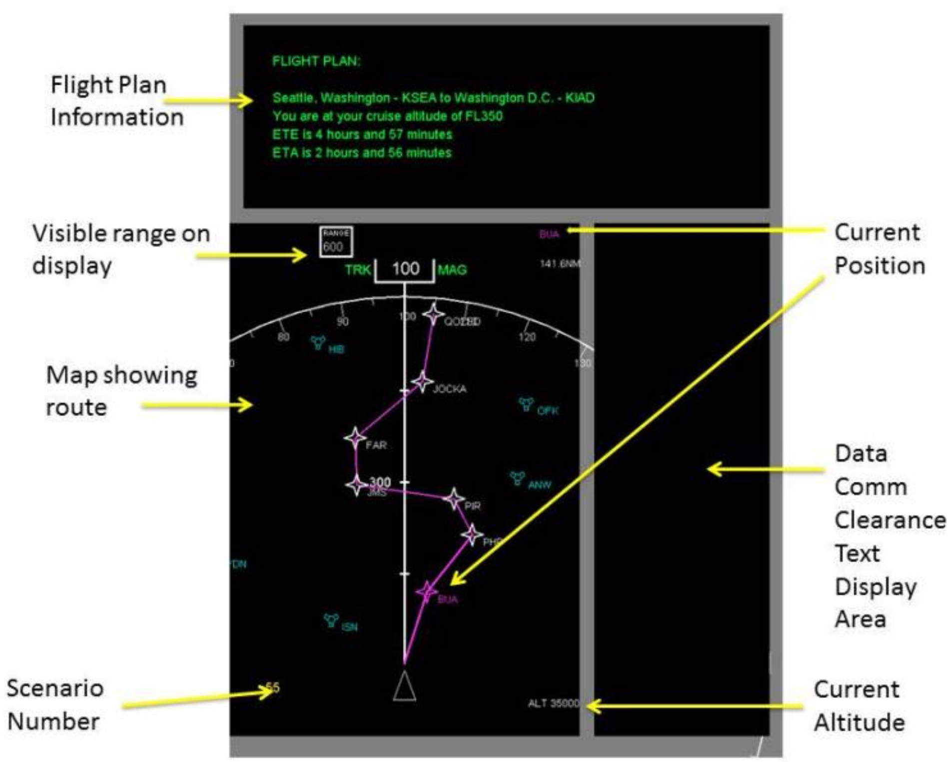



**Figure 1. Example of interface for DC-MAT showing flight plan, graphic area, and text area.**

### 2.6.2. Method 2: Dynamic Display of DataComm Information During Flight Simulation

The second method was to present text and graphic concepts that allowed pilots to interact with the display as they would in the cockpit environment. For these studies the displays were presented to pilots within a flight simulation that provide them with a specific flight scenario. The aircraft was flown via the flight management system and the pilot was presented with clearances during the flight. Pilots evaluated clearances and indicated WILCO or UNABLE. If the pilot indicated UNABLE they were able to create DMs to request clearances based on the scenario.. Figure 2 is a photo of the flight simulator, and figures 3 through 7 illustrate examples of different interfaces using text and hybrid concepts. Volume 2 describes the simulator in more detail including hardware, software and example interfaces.

**Figure 2. Two LCD Touch Screen Displays Inside the Cockpit. Yoke, Throttles and Flaps are also visible.**

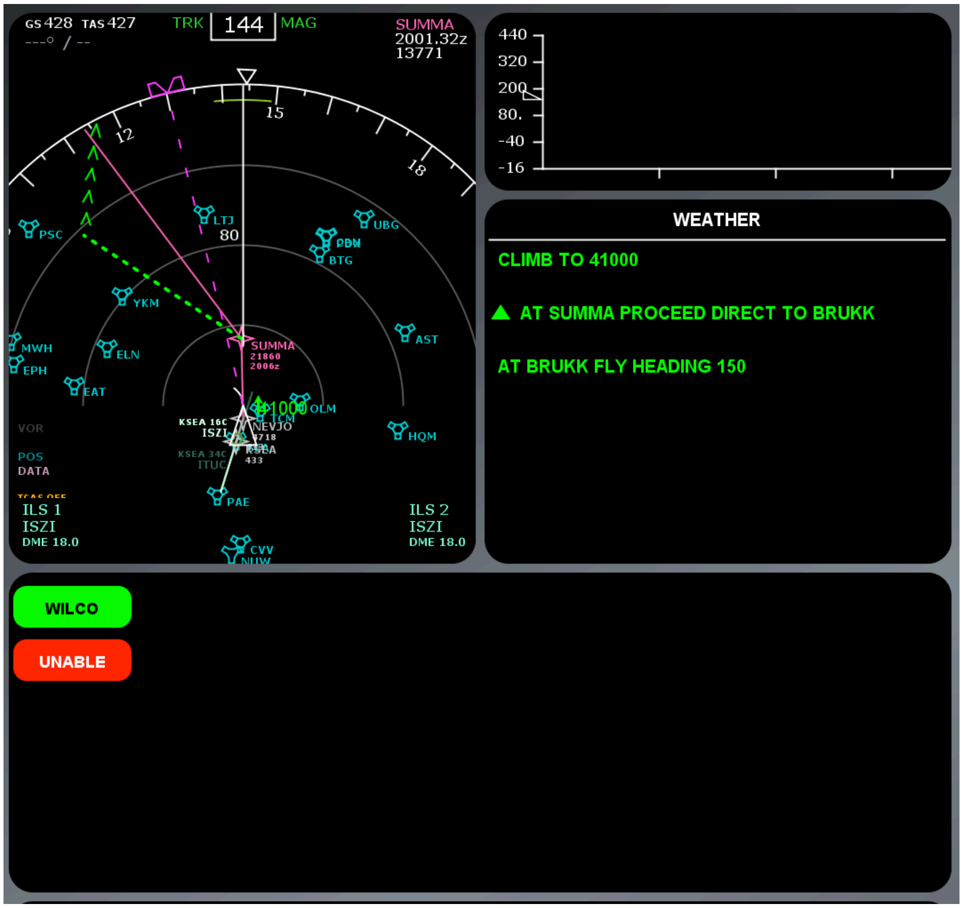



**Figure 3. TextGen Interface Illustrating Presentation of a Clearance.**

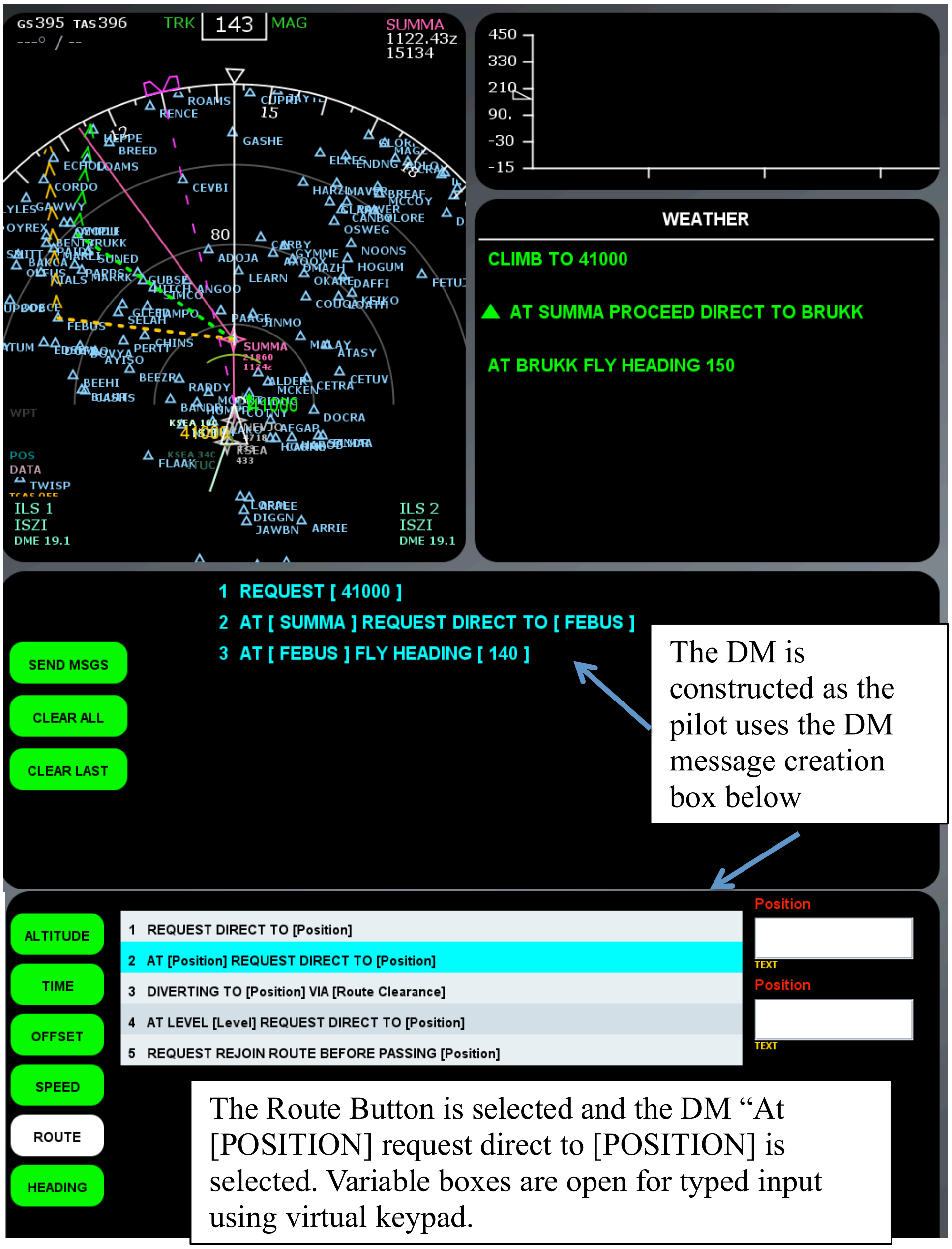



**Figure 4. TextGen Interface After Pilot Selects Unable. Pilot is able to create a DM response.**


**Figure 5. GraphicGen Interface Illustrating Arrival of a Clearance.**

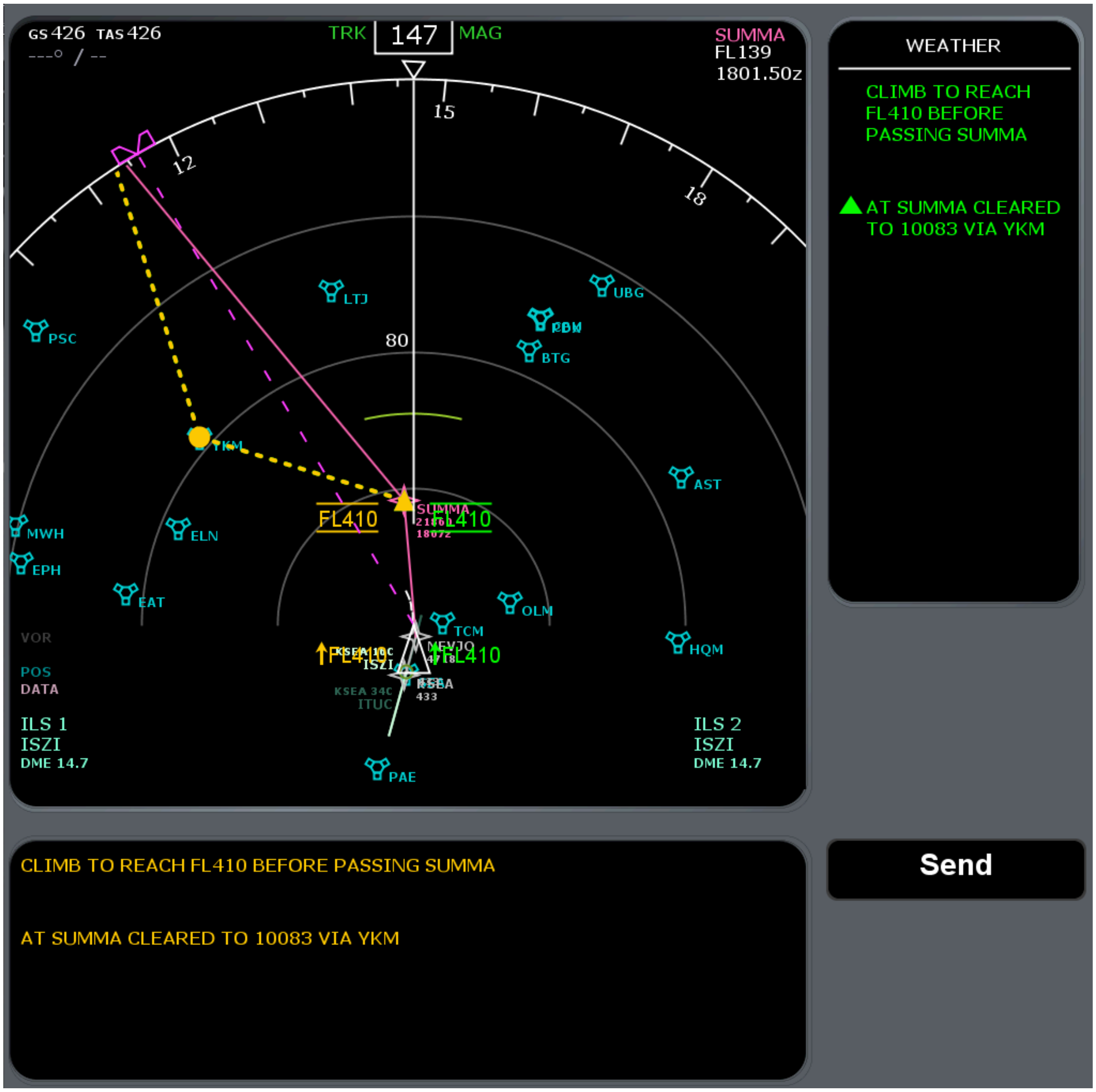



**Figure 6. GraphicGen Interface Illustrating Screen After Pilot Selects Unable.**

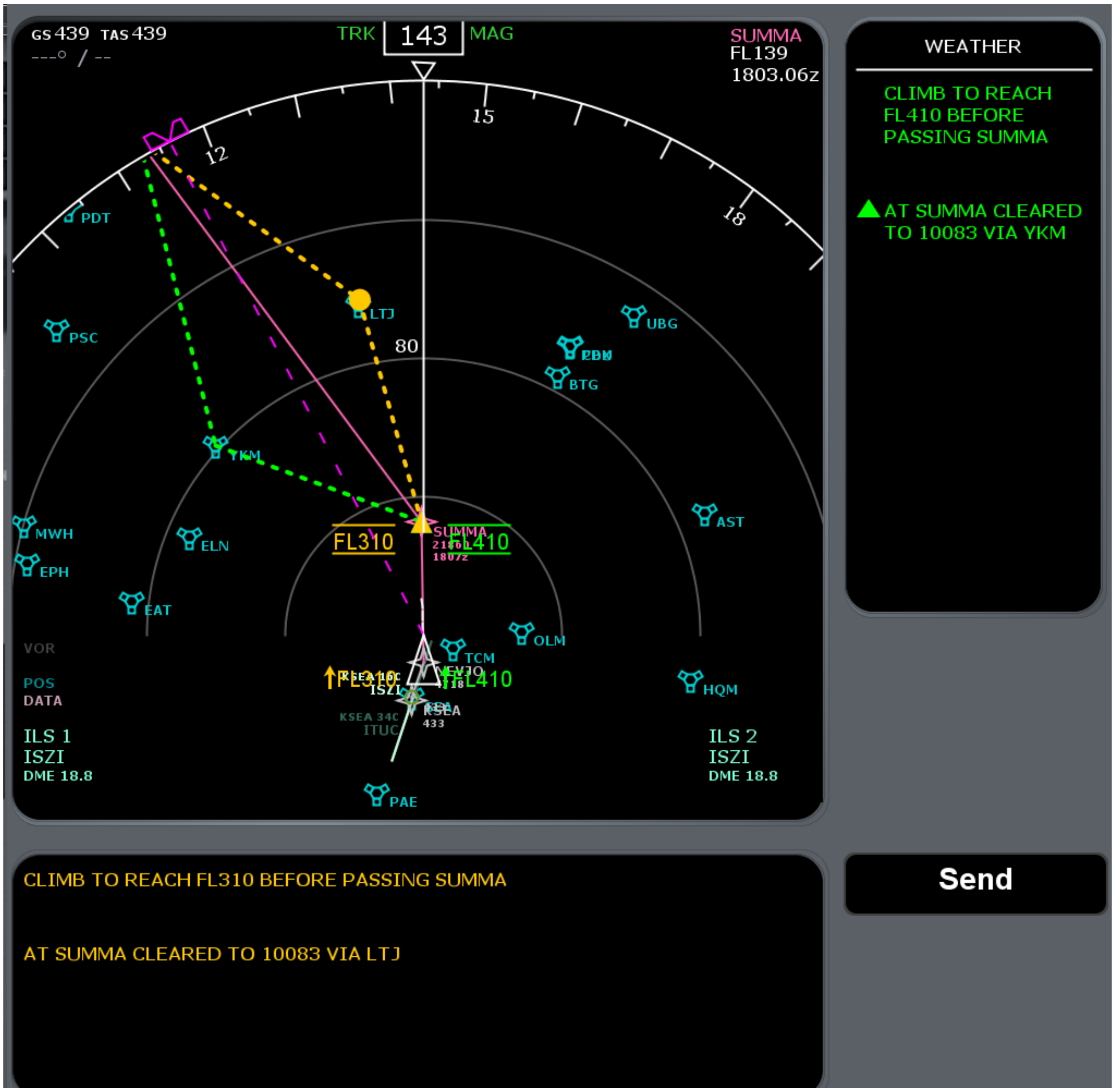



**Figure 7. Example of GraphicGen After Pilot has Manipulated the Graphic to Create DM.**

# 3. Conclusions

DataComm is a critical enabling technology for the Next Generation (NextGen) airspace. The use of datalink for communication between pilots and air traffic control requires significant consideration of human factors challenges that arise with the introduction of this new technology. Currently voice communication limits the amount of information that can be sent to a pilot. DataComm will allow more complex clearances to be sent to the cockpit, including 4D trajectories. To date DataComm messages have primarily been tested in the oceanic environment under the Future Air Navigation System (FANS) using text messages. However, during en route TBO text is not an ideal presentation format given the spatial information that must be passed to the pilot or to ATC.

This is one of the first studies to directly compare text display of clearances and DMs to graphic and/or hybrid presentations of graphics and text. The research findings (presented in Vol 2) indicate that when three or more elements are specified in a clearance, presentation methods that include graphics and text result in better human performance outcomes than text alone.

The development of human factors recommendations to support human factors specialists in the FAA Aircraft Certification Service and Flight Standards Services is one of the major contributions of this research (Appendix 1). Additionally, a tool that can be used for assessment of graphic presentations was created: the Data Communication-Methods Assessment Tool (Appendix 2). An additional contribution included lessons learned about specific UMs and DMs and the concatenation of messages. This information (Appendix 3 and Vol 2) can support the evaluation or consideration of specific messages in the SC-214 data set.

The limitations of this research are that the clearances and DMs were evaluated using part task simulations, both static and dynamic with one pilot rather than a crew. Therefore information related to specific performance measures of response time and errors must be considered under these conditions. As technology advances and more NextGen capabilities are identified, it will be important to continue to develop and evaluate additional human factors guidelines. In addition, it might be helpful to evaluate appropriate samples of prospective presentation formats under full task simulation to ensure that they can be used within a realistic flight scenario.

The research outputs presented in Vol 1 and 2 provide critical information toward the development of DataComm for NextGen.

# 4. References


Bakowskil, D. L., Foylez, D. C., Hooeyl, B. L., Meyeri, G. R., & Wolterl, C. A. (2012). DataComm in flight deck surface trajectory-based operations. Advances in Human Aspects of Aviation, 15, 259.

Cardosi, K., Lennertz, T., Donohoe, C. (2010). *Human Factors Research Plan for Flight Deck Data Communications*. Human Factors Research and Engineering Group. Boston MA: USDOT Volpe National Transportation Systems Center.

Federal Aviation Administration. Department of Transportation, (2010). *Guidelines for design approval of aircraft data link communication systems supporting air traffic services (ATS).* (AC 20-140A). Retrieved from Federal Aviation Administration website: www.faa.gov

Federal Aviation Administration, Department of Transportation (1987). *Transport Category Airplane Electronic Display System*s. (AC 25-11). Retrieved from Federal Aviation Administration website: www.faa.gov

Hahn, E. C., & Hansman, R. J. (1992). Experimental Studies on the Effect of Automation on Pilot Situational Awareness in the Datalink ATC Environment,(SAE Tech. Report No. 922002). Warrendale, PA: Society of Automotive Engineers International

Honeywell (2011). CPDLC Procedures. Recommendations for General System Performance Requirements, Design of Standard Operating Procedures and Operating Limitations for CPDLC. Final report: Document No. DTFAWA-10-A-80031-MYY-01-ZZ

Hoogeboom, P., & Huisman, H. (1996). 4D ATM cockpit: Set-up and initial evaluation. *ICAS PROCEEDINGS, 20.* pp. 2057-2064.

Lancaster, J., Riddle, K., Feyereisen, T., Olufinboba, O., Rogers, B., Gannon, A., Suddreth, J., He, G. (2011). *Trajectory Based Operations and the Legacy Flight Deck: Envisioning Design Enhancements for the Flight Crew.* Golden Valley, MN: Honeywell Advanced Technology

Liggett, K. K., & Gallimore, J. J. (2002). The effects of frame of reference and HMD symbology on control reversal errors. *Aviation, Space, and Environmental Medicine, 73*(102), 111.

McGann, A., Lozito, S., and Corker, K. (2001). Flight Deck Data Link Displays: An Evaluation of Textual and Graphical Implementations. Tech. Report, NAS/TM-2001-211384.

RTCA (2003). *Minimal Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps,* (DO-257A), Washington D.C.

RTCA (2012). *Standards for Air Traffic Data Communication Services.* (RTCA SC-214 / EUROCAE WG-78).

Wickens, C. D., Liang, C. C., Prevett, T., & Olmos, O. (1996). Electronic maps for terminal area navigation: Effects of frame of reference and dimensionality. *The International Journal of Aviation Psychology, 6*(3), 241-271.

Wickens, C. D., Vincow, M., & Yeh, M. (2005). Design applications of visual spatial thinking: The importance of frame of reference. *The Cambridge Handbook of Visuospatial Thinking,* 383-425.

# 5. Appendix 1: Human Factors Guidelines and Recommendations

Each guideline or recommendation is presented in a table format that includes the Number, Category, Title, Recommendation (including graphic examples) and Rationale. Example graphics are provided in the Rationale section. A recommendation may be several pages in length; therefore each recommendation begins on a separate page to more easily identify the beginning of a new recommendation. The recommendations listed in this report were reviewed by the sponsor and collaborators from Cessna and reflect their inputs.

## 5.1. Definitions

ATC clearances are created through the use of UMs. UMs consist of a message and one or more variables called elements. For example the UM “At [LEVEL] proceed direct to [POSITION] is one UM with two elements. A clearance is composed of one UM, or a concatenation of UMs with one or more elements. Within the recommendations, the use of “one element” or any other number of elements indicates the number of variables for single and concatenated messages.

## 5.2. Graphic and Textual Display of UMs and DMs

### 5.2.1. Graphics versus Text

<table>
<tr><td>Number 1</td><td>Category: Graphic and Textual Display of UMs and DMs</td></tr>
<tr><td colspan="2">Title: Graphics vs. Text</td></tr>
<tr><td colspan="2">Recommendation: DataComm displays for the flight deck should use a hybrid approach with both graphics and textual presentation of UMs/DMs.<br><br>The only case in which graphics are not required would be for one element clearances. While graphics may not be necessary for one element clearances, the research did not evaluate every one element clearance. Also, to maintain similarity across all displays, one- element clearances should also have a graphic. Pilots might wonder why graphics are missing in those cases and distrust the displayed information.<br><br>With respect to DMs, when the pilot creates a DM, a graphic illustrating that message should be provided along with the textual message before the pilot “sends” the DM. This allows the pilot to cross-check that the meaning of the text message matches the intent of the request before sending the DM.</td></tr>
<tr><td colspan="2">Rationale: The human-in-the-loop (HITL) research studies illustrated that text alone can be ambiguous and adding graphics improves performance. The only case in which graphics did not show some advantage was for single element clearances (e.g., CLIMB TO [level]. At times graphics can also be ambiguous, especially when a message is conditional. E.g. UM AT [time] CLIMB TO [Altitude]. Pilots reported that they preferred graphics and want to be able to crosscheck the graphics with the text. Procedures for two-crew aircraft recommend crosschecking the clearance with each pilot (Honeywell, 2011) including the possibility of reading the clearance aloud. Having text of the UM/DM supports crosscheck procedures. A graphic itself can help to</td></tr>
</table>

disambiguate a text message when well designed. Example graphics are illustrated in Rec 1-Fig A and Rec 1-Fig B below.

Others suggest that textual information may not be sufficient to support 4DT. Graphic displays could show the meaning and consequence in position, altitude, speed, time or other relevant elements to support the textual DataComm message.

Results of the human-in-the-loop research generally found an advantage over hybrid display of graphics and text compared to text alone. However, too much information for both graphics and text, or too many elements in a UM/DM can decrease overall performance.

Additional references that found graphics improved performance or were preferred by pilots include:

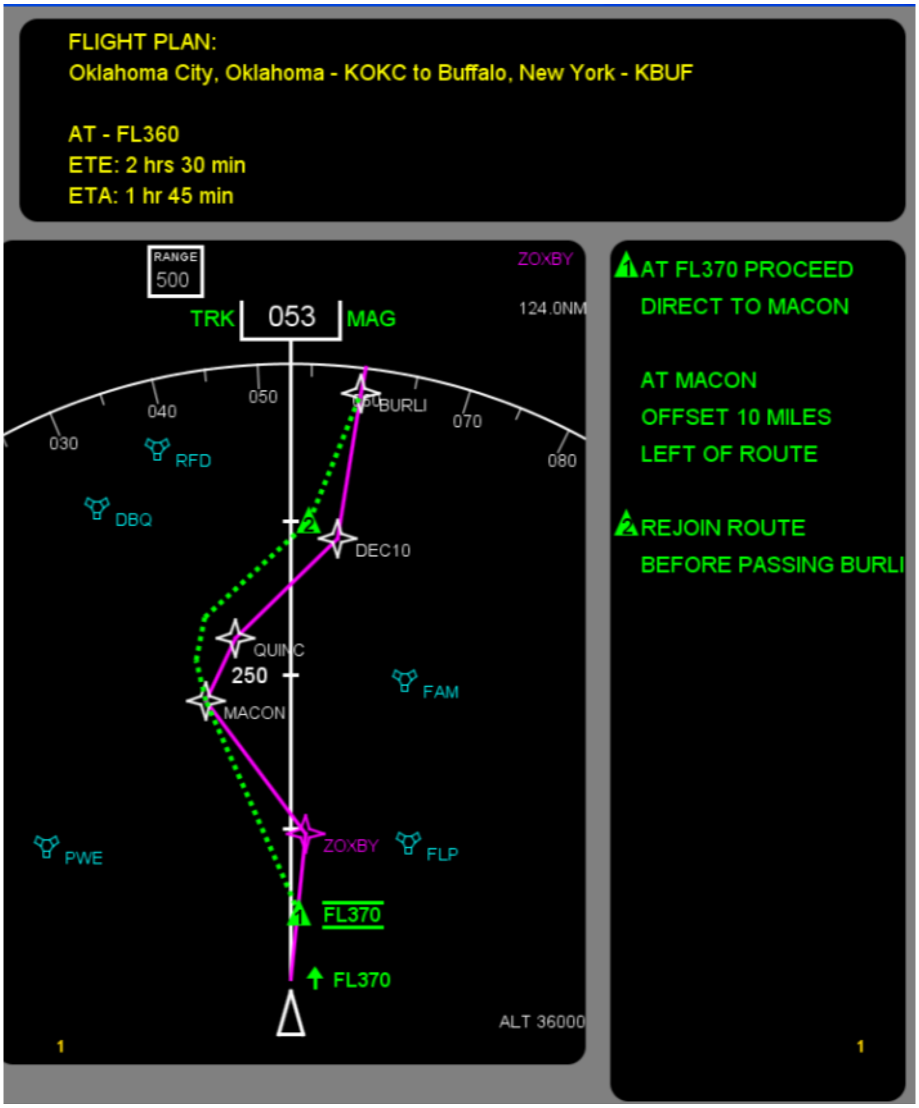
Bakowskil, D. L., Foylez, D. C., Hooeyl, B. L., Meyeri, G. R., & Wolterl, C. A. (2012). DataComm in flight deck surface trajectory-based operations. Advances in Human Aspects of Aviation, 15, 259.

Hahn, E. C., & Hansman, R. J. (1992). Experimental Studies on the Effect of Automation on Pilot Situational Awareness in the Datalink ATC Environment,(SAE Tech. Report No. 922002). Warrendale, PA: Society of Automotive Engineers International

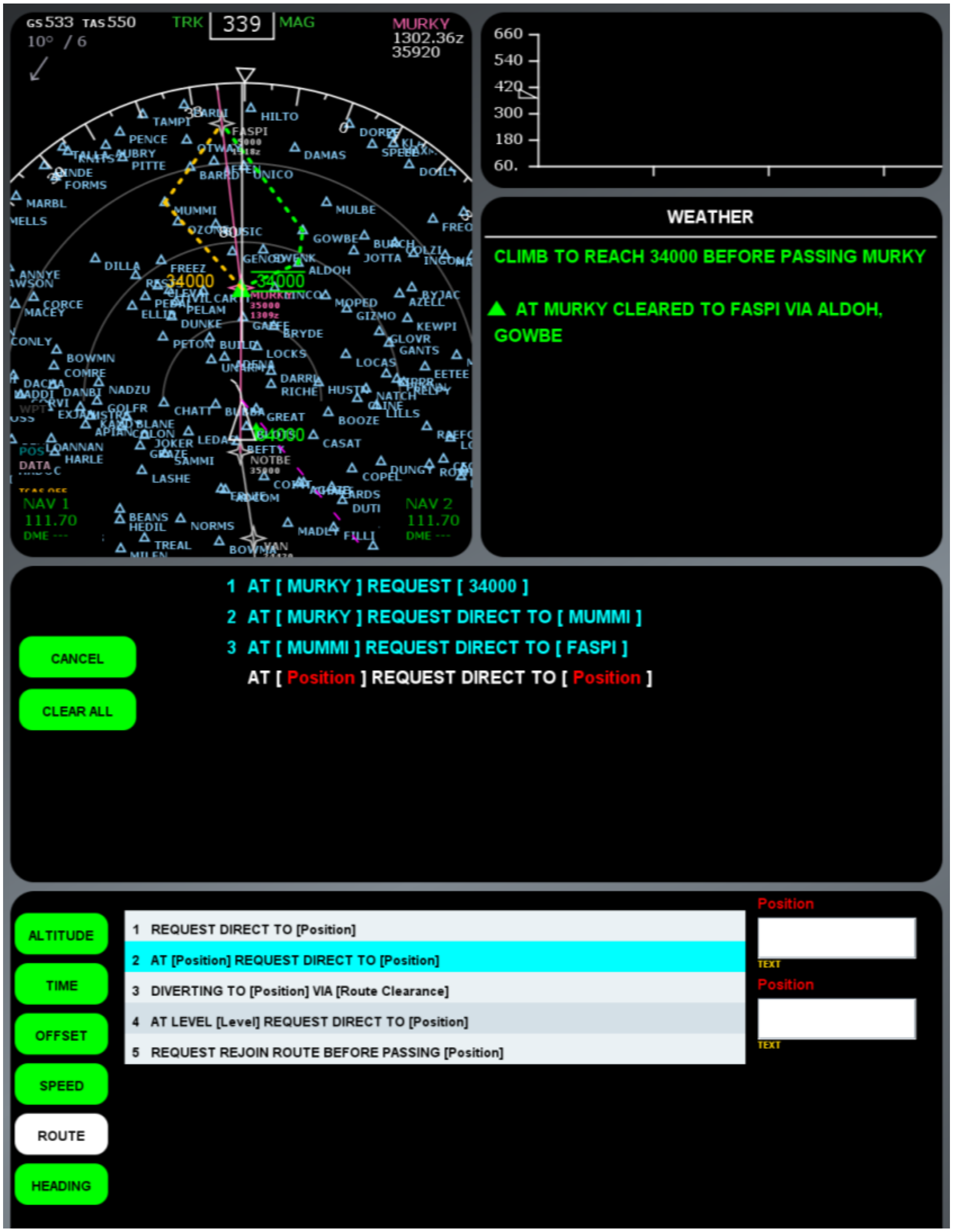
Hoogeboom, P., & Huisman, H. (1996). 4D ATM cockpit: Set-up and initial evaluation. *ICAS PROCEEDINGS, 20.* pp. 2057-2064.

Lancaster, J., Riddle, K., Feyereisen, T., Olufinboba, O., Rogers, B., Gannon, A., Suddreth, J., He, G. (2.011). Trajectory Based Operations and the Legacy Flight Deck: Envisioning Design Enhancements for the Flight Crew.

McGann, A., Lozito, S., and Corker, K. (2001). Flight Deck Data Link Displays: An Evaluation of Textual and Graphical Implementations. Tech. Report, NAS/TM-2001-211384.




Rec 1-Fig A: Example of graphic and text hybrid display of a UM. Magenta line indicates pilot current path. Green line and symbols indicated UM clearance.



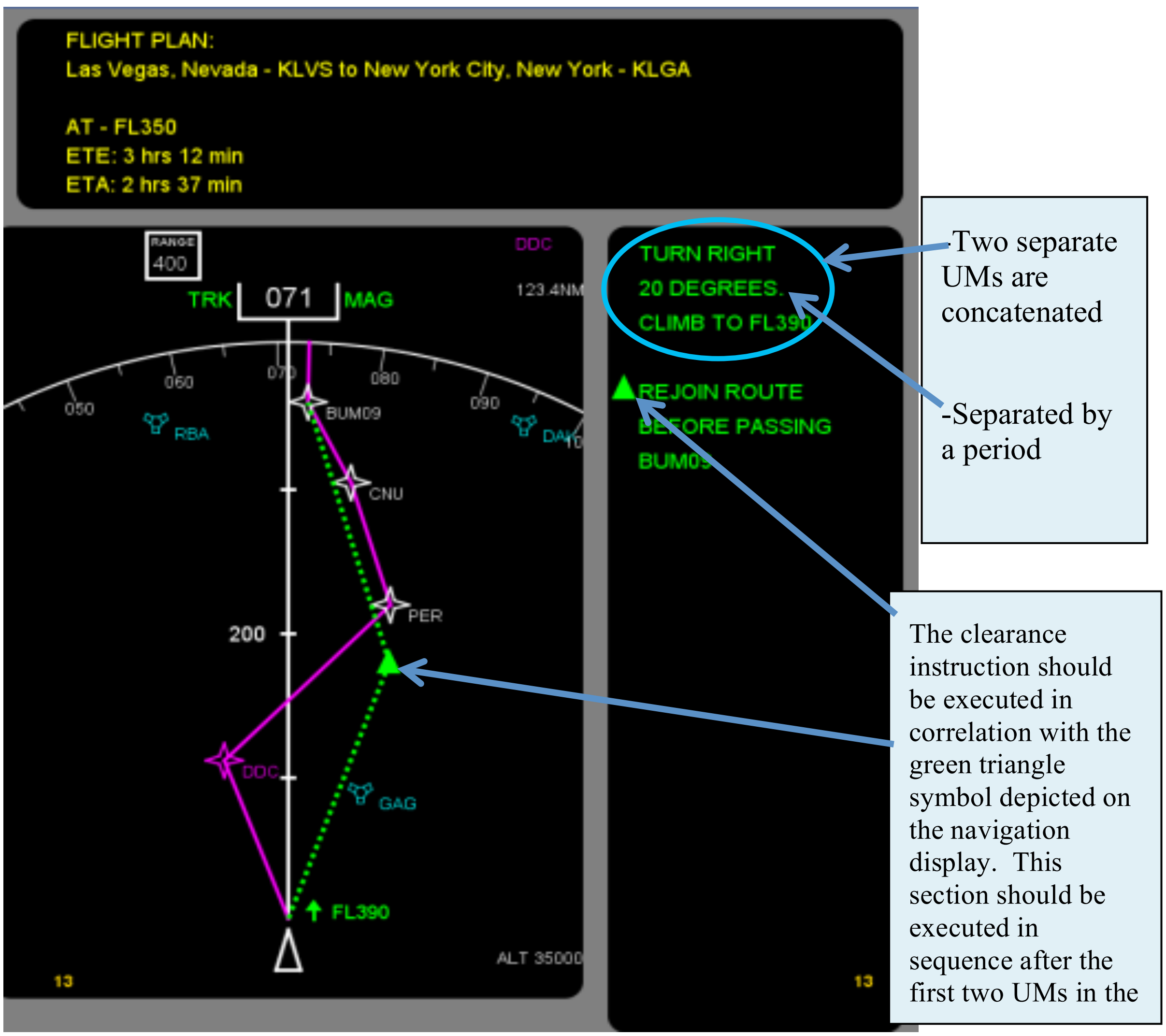

Rec 1- Fig B. Example of Graphic and text hybrid display with UM and DM sections.

### 5.2.2. Coordinating Text with Graphics

| Number 2 | Graphic and Textual Display of UMs and DMs |
|---|---|
| Title: Coordinating Text with Graphics | |

**Recommendation**: When text and graphics are presented separately, there should be symbols or other design methods that illustrate the one-to-one match of the text and the coordinating graphic.

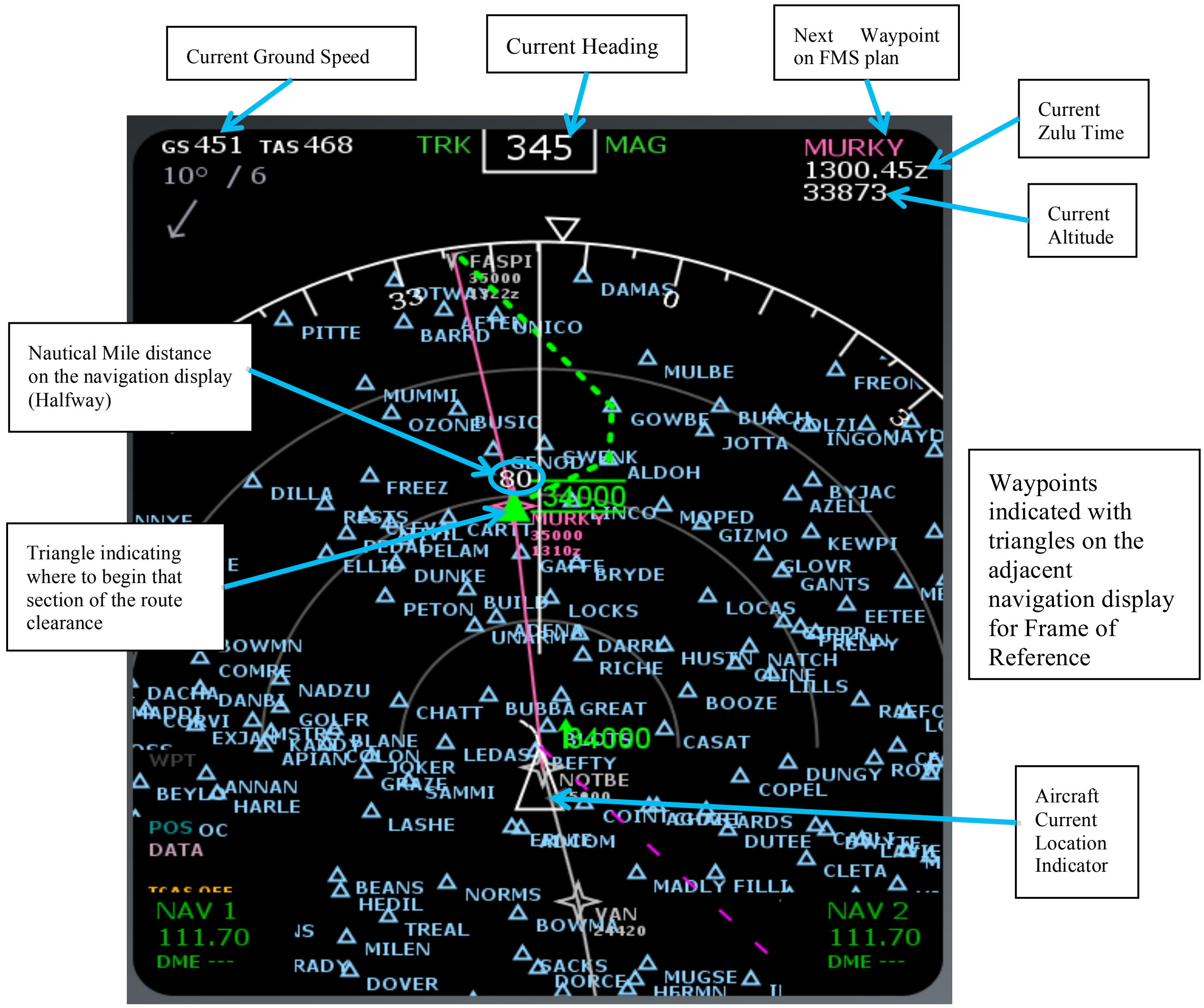
**Rationale**: When text and graphics are presented separately, there should be symbols or other design methods that illustrate the one-to-one match of the text and the coordinating graphic. For example the text may have a symbol next to it that matches the symbol on the display or the text and graphics may have a coordinated number. The concept is to ensure that the pilot is able to crosscheck the graphic with the text. Figure Rec 2-Fig A illustrates the concept.




Rec 2- Fig A. An Example of Coordinating Text with Graphics

### 5.2.3. Graphic Spatial Frame of Reference

| Number 3 | Graphic and Textual Display of UMs and DMs |
|---|---|
| Title Graphic Spatial Frame of Reference | |
| **Recommendation**: The graphic representation of UMs/DMs should provide the pilot with a spatial frame of reference that includes position of their aircraft within the airspace. All graphic information should be designed to align with that frame of reference. For example, electronic map displays provide a spatial frame of reference and are common in aircraft as well as other pilot tools such as GPS systems, EFB, and route maps. Figure 1 is an electronic navigation display showing ownership and all information related to current time as well as flight path, heading, altitude, and speed. | |
| **Rationale**: Research on frame of reference in aviation has shown it is critical to spatial orientation, both in the air and for ground reference. The graphic should include two frames of reference one based on the user perspective (ego-centric) and a world frame of reference. Figure Rec 3-Fig A illustrates a navigation display with an exocentric frame of reference, that is, the pilot eye point is above the aircraft.<br>• Liggett, K. K., & Gallimore, J. J. (2002). The effects of frame of reference and HMD symbology on control reversal errors. *Aviation, Space, and Environmental Medicine, 73*(102), 111.<br>• Wickens, C. D., Vincow, M., & Yeh, M. (2005). Design applications of visual spatial thinking: The importance of frame of reference. *The Cambridge Handbook of Visuospatial Thinking,* 383-425.<br>• Wickens, C. D., Liang, C. C., Prevett, T., & Olmos, O. (1996). Electronic maps for terminal area navigation: Effects of frame of reference and dimensionality. *The International Journal of Aviation Psychology, 6*(3), 241-271. | |




Rec 3 – Fig A. Example of a navigation display (ND) with an exocentric frame of reference (FOR).

### 5.2.4. Use of Electronic Map Displays

| | |
|---|---|
| Number 4 | Category: Graphic and Textual Display of UMs and DMs |
| Title: Use of Electronic Map Displays for Depicting UMs and DMs | |
| **Recommendation**: When using graphics on existing aircraft map displays, such as the navigation display, or when designing new standalone graphic map displays for DataComm, designers should use RTCA D0-257A "Minimal Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps" as a standard when designing UM/DM graphics. | |
| **Rationale**: Existing standards based on research and currently in use by the FAA for certification must be followed. | |

### 5.2.5. Minimum Graphics Information on Flight Deck Map DataComm Displays

| Number 5 | Category: Graphic and Textual Display of UMs and DMs |
|---|---|
| Title: Minimum Graphic Information Requirements When Using a Map Display | |

**Recommendation**: The designer should include the minimum requirements for map displays as indicated in the RTCA D0-257A "Minimal Operational Performance Standards for Depiction of Navigation Information on Electronic Map Displays" and listed in the Table 1 below.

Rec-5 Table 1. Required as Per RTCA DO 257-A, 2003, Table 2-1, pg 18

| | |
|---|---|
| Map Depiction | Aircraft location |
| | Desired Path |
| | Active Fix |
| | Next Fix |
| Operating Status | Indication of map range |
| | Indication of map orientation |
| Control Functions | Select map range |
| | De-clutter |
| Minimum Symbol Set | Waypoints |
| | Airport |
| | VOR |
| | NDB |
| | Intersection |
| | Aircraft ownship |

The designer should include the additional minimum information listed in Table 2 for spatial UM messages from ATC (ATC clearances) and DMs (pilot requests). These are UMs/ DMs that affect the spatial location of the aircraft and routing. These recommendations are not related to UMs/DMs instructions that do not affect the route of flight (e.g., transfer of communications, contact/monitor, and report requests).

Rec 5-Table 2. DataComm **Additional Requirements** for graphics for UMs from ATC and DMs from pilots (used to review before sending DM to ATC.)

| | | |
|---|---|---|
| Map Depiction | UM/DM new flight path (route). The new path should be a different color than the current path and use a different line style. | Examples Under Rationale<br>Figure B |
| Symbols | UM/DM next fix | Figure B |
| | UM/DM waypoints | Figure B |
| | When UM/DM is conditional based on time, display time at which to begin clearance. | Figure C |
| | Current altitude | Figure B |
| | When UM/DM is conditional based on position (location), display location at which to begin clearance. | Figure B |
| | When UM/DM is conditional based on speed, display current speed and speed at which to begin clearance. | No figure, similar to time |
| | Any spatial element specified in the UM/DM. Element is defined as the variable within the clearance. For example Climb to [Level], where the word in brackets is the element. A symbol would be provided for the altitude. | Table 3 lists examples UM/DM elements that require symbols.<br>Figure B |
| | Any instruction in a UM/DM that provides an indication to a spatial event or location.<br>For example, AT [position] **OFFSET** [specified distance] [direction] OF ROUTE. The instruction OFFSET should include a symbol to help specify the command of OFFSET. | Figure E<br>Table 3 lists example instructions that require graphics symbol to specify instruction along with element. |

| | | |
|---|---|---|
| | Use symbols to clearly indicate the sequence of clearances when concatenated UMs/DMs are not to be completed simultaneously or at pilot discretion. | Figure B, F, G |
| | Symbol and label for latitude/longitude or most current Navigation Reference System (NRS) nomenclature, when no other specifically named waypoint is available. | Figure H |

Table 3. List of elements that require symbols on map display

| | |
|---|---|
| Elements | Position (location)<br>NRS or Lat/Long |
| | Current Time, Zulu |
| | Time to begin clearance, Zulu |
| | Speed |
| | Altitude or Level |
| | Heading (degrees) |
| | Direction (right, left) |
| Instructions | Rejoin (position by which rejoin must be complete) |
| | Offset* |
| | Crossing |

**Rationale**:

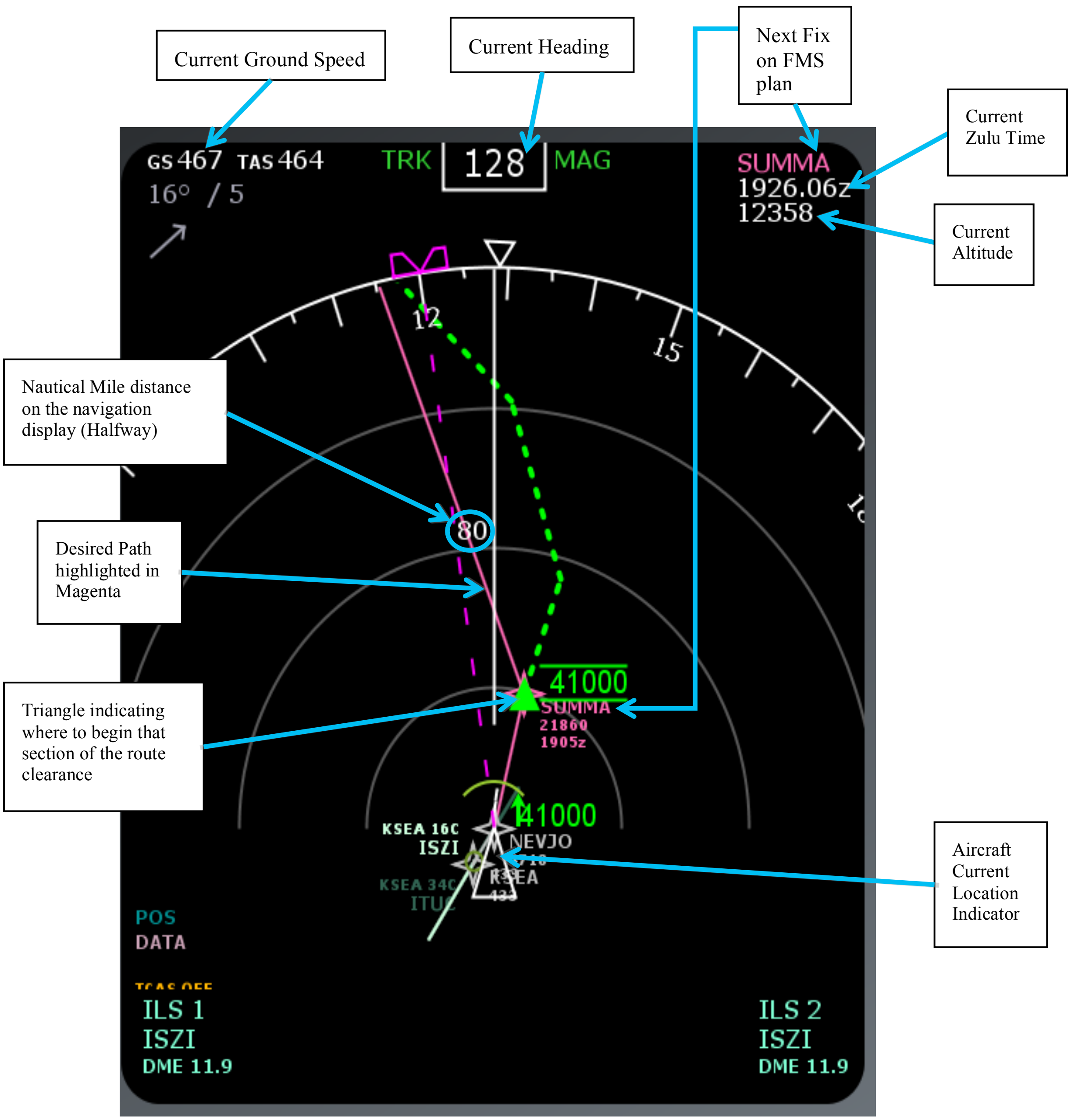
The research conducted during this project utilized a navigation map display (ND) so that minimal updates could be made to existing cockpits that utilize an ND display.

Experiments were conducted measuring 1) time to interpret and respond with accept or reject to a UM, 2) percent correct responses, 3) time to create a DM, and 4) errors creating DMs. Results showed that graphics presented along with text presented nearby (proximal) decreased response time and increased the percent of correct answers.

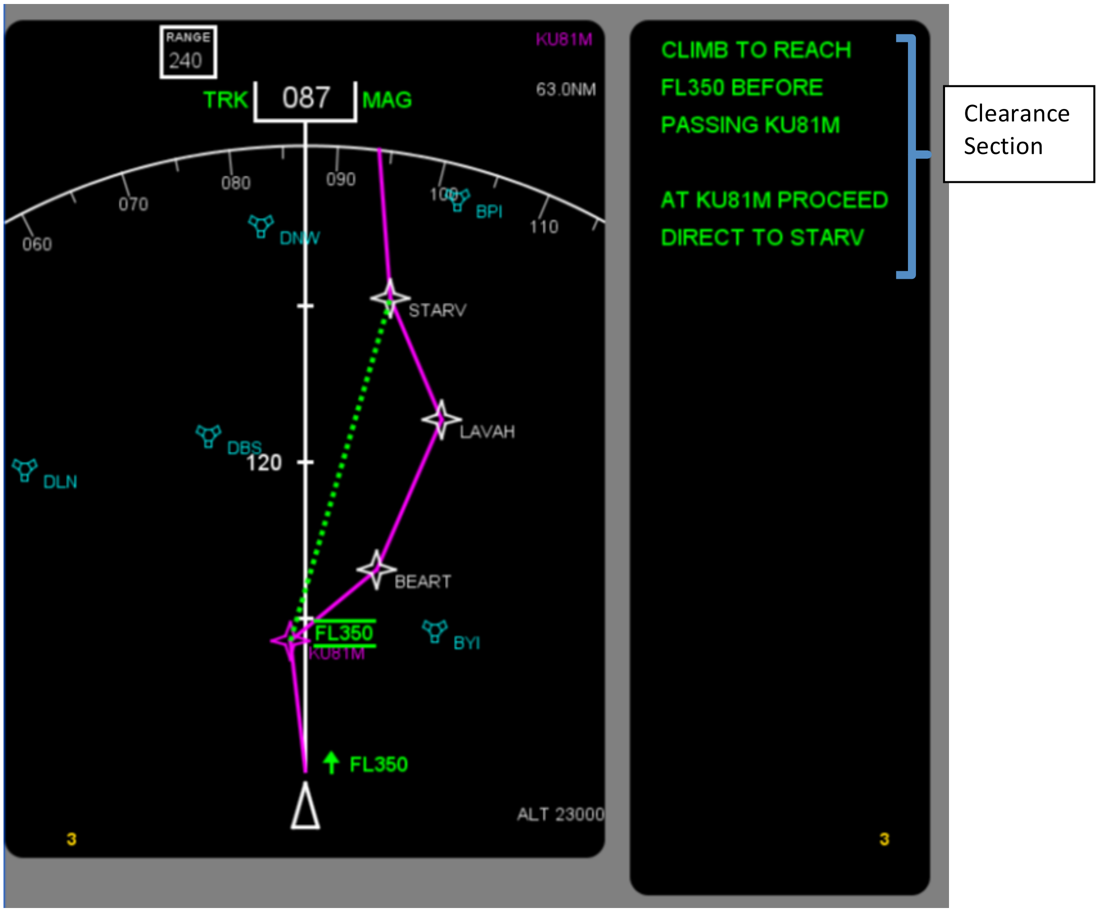
The amount of the performance enhancement depends on the specific UM and the number of elements in a clearance or it's complexity. As a minimum, graphics should provide the pilots with a way to compare the new cleared or requested flight path with the current route or current condition and future aircraft route in 4D space (including time).

Offset: Lancaster, et al (2011) recommended showing the beginning and end of an offset track. However, since the user may chose the range of any map based display, the beginning and end may not be visible at the same time. The pilot will need to change range in some circumstances.

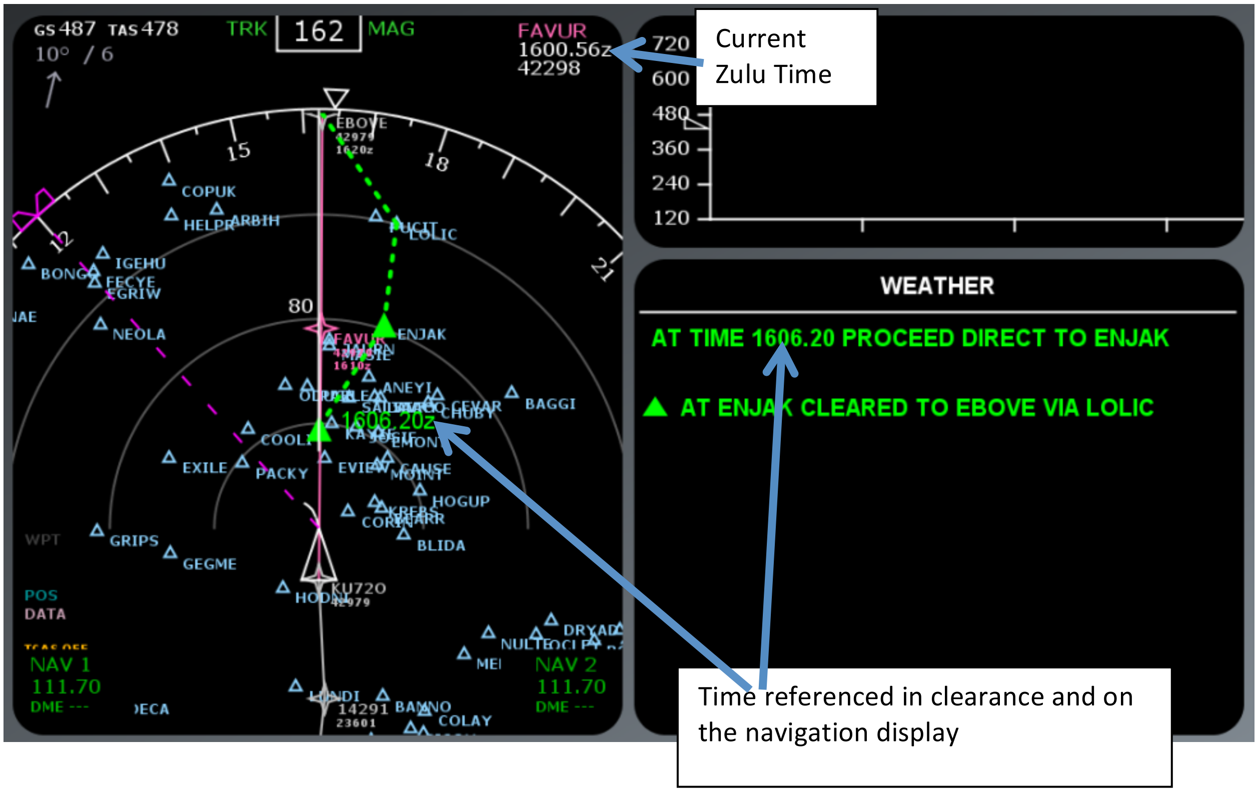
Example Graphics are illustrated below.



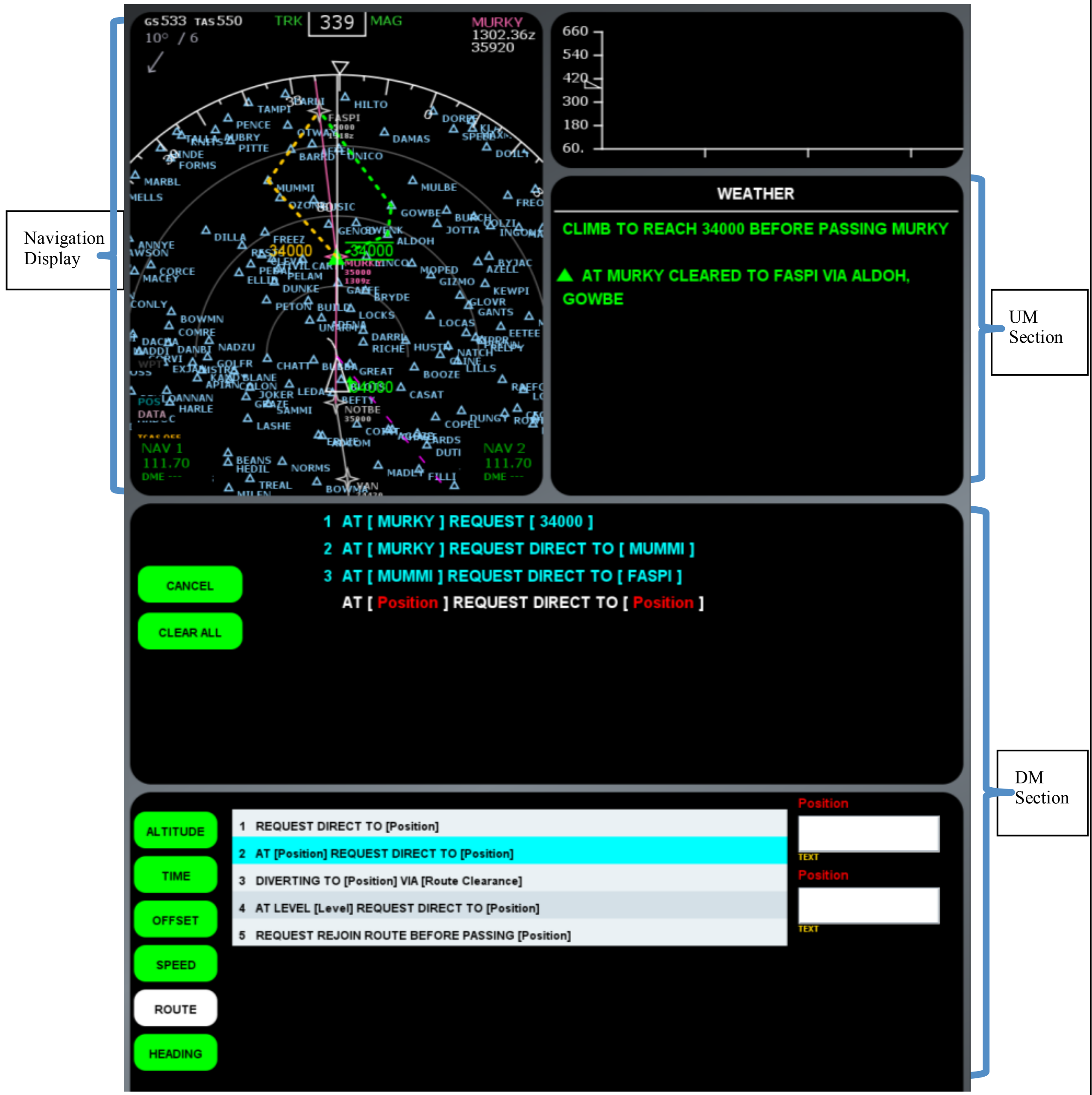

Rec 5 – Fig A Example of Existing Navigation Display (ND) with added UM Graphic Reroute.



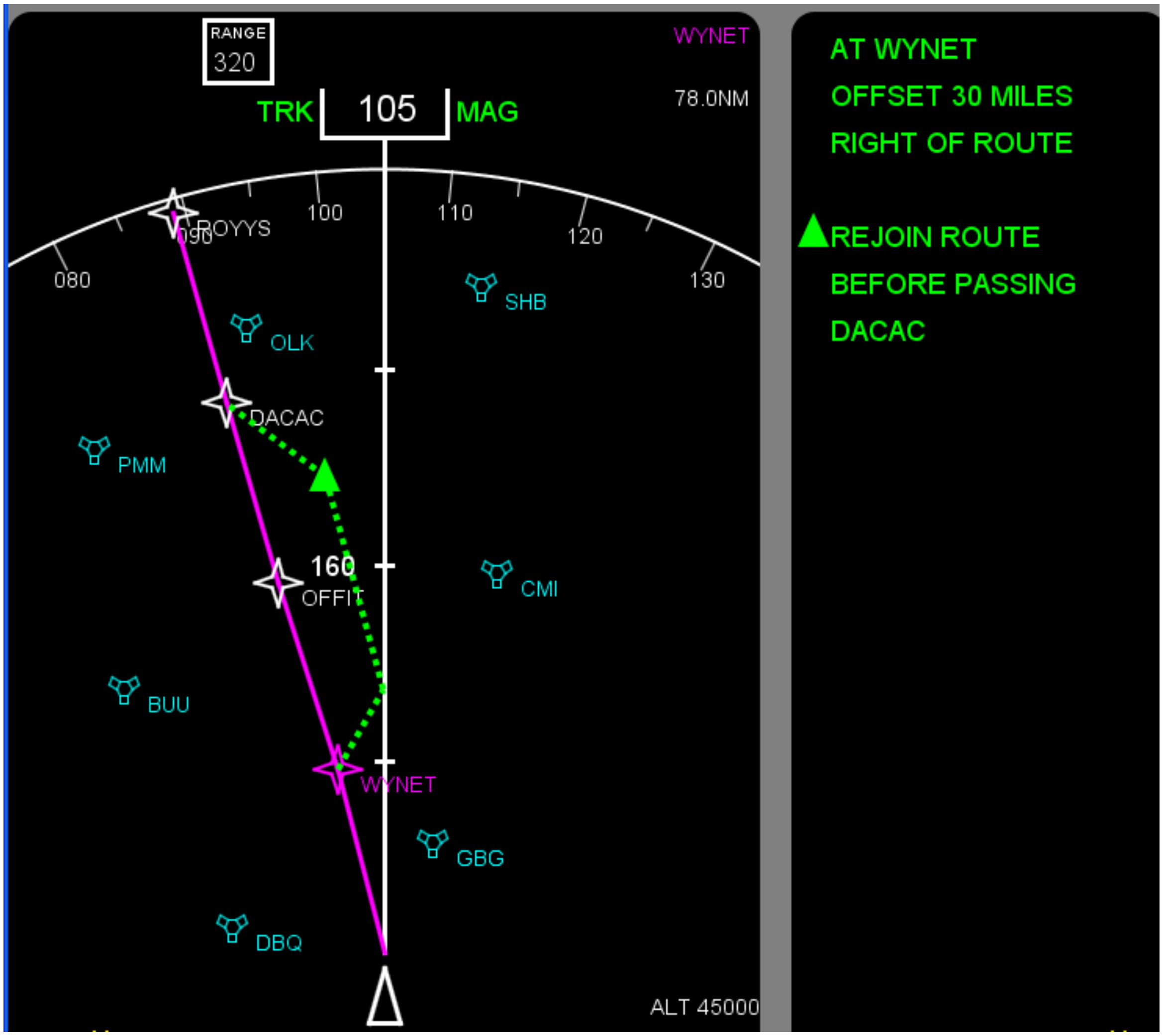

Rec 5-Figure B. Example Navigation Display with Text Clearance Section.



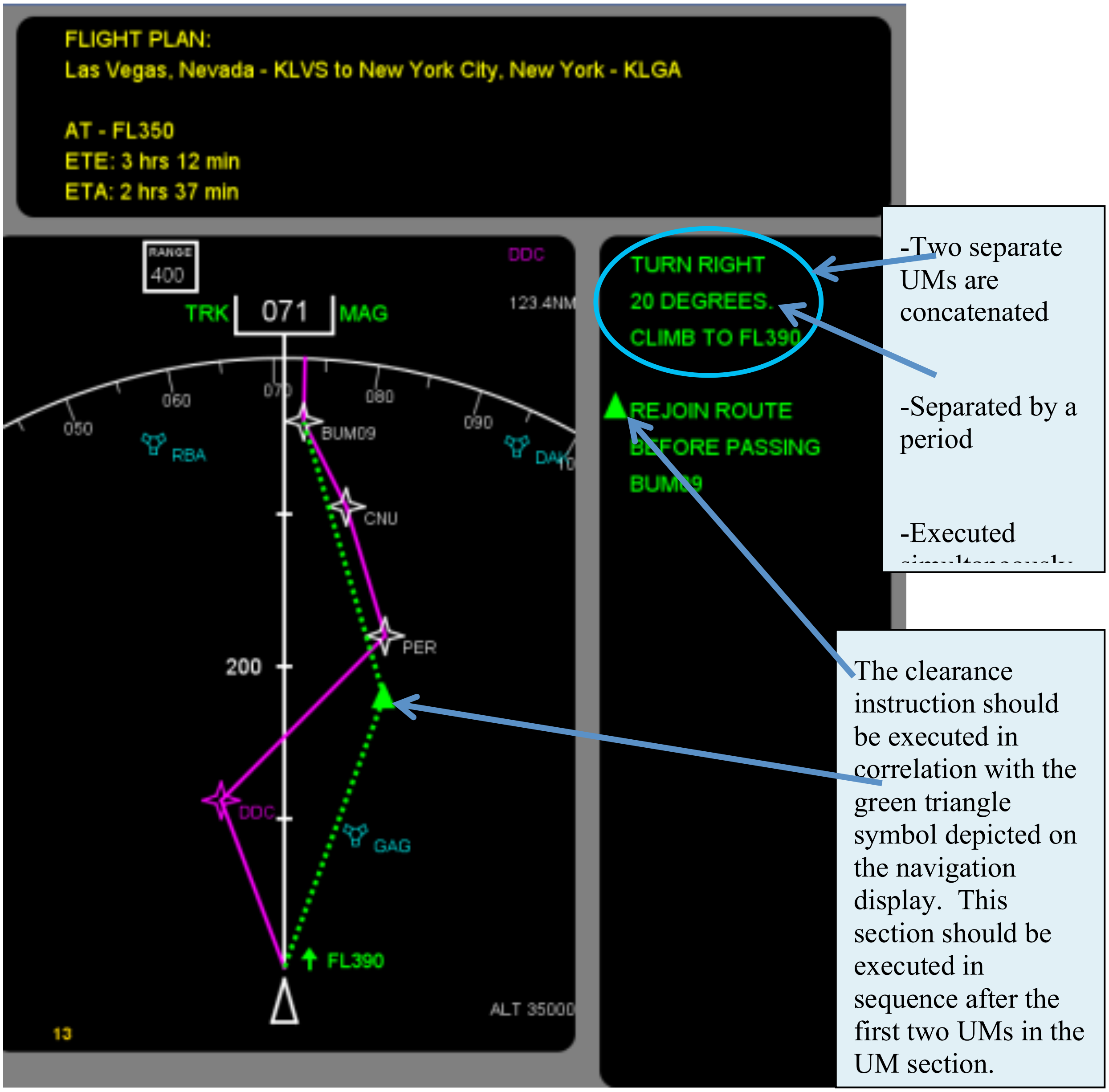

Rec 5-Figure C. Waypoint with Labeled Times to Begin Clearance.



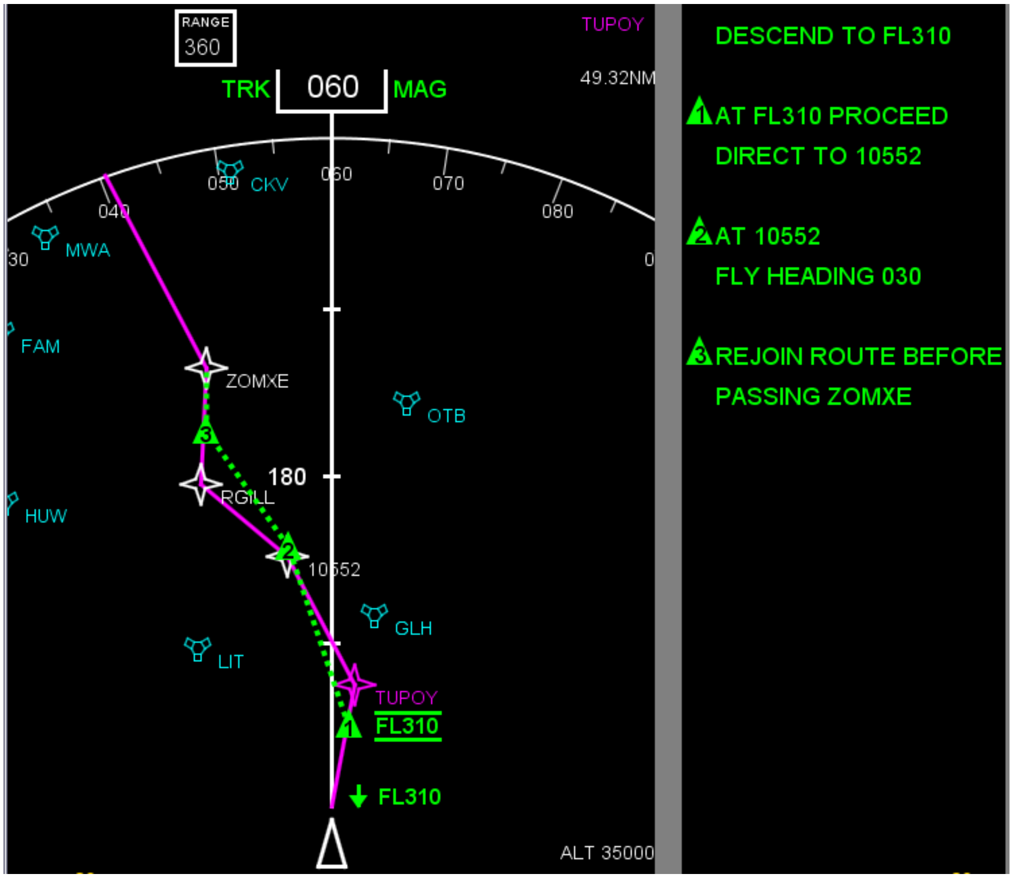

Rec 5-Fig D. Adjacent Placement of Navigation Display, UM Section and DM Section.



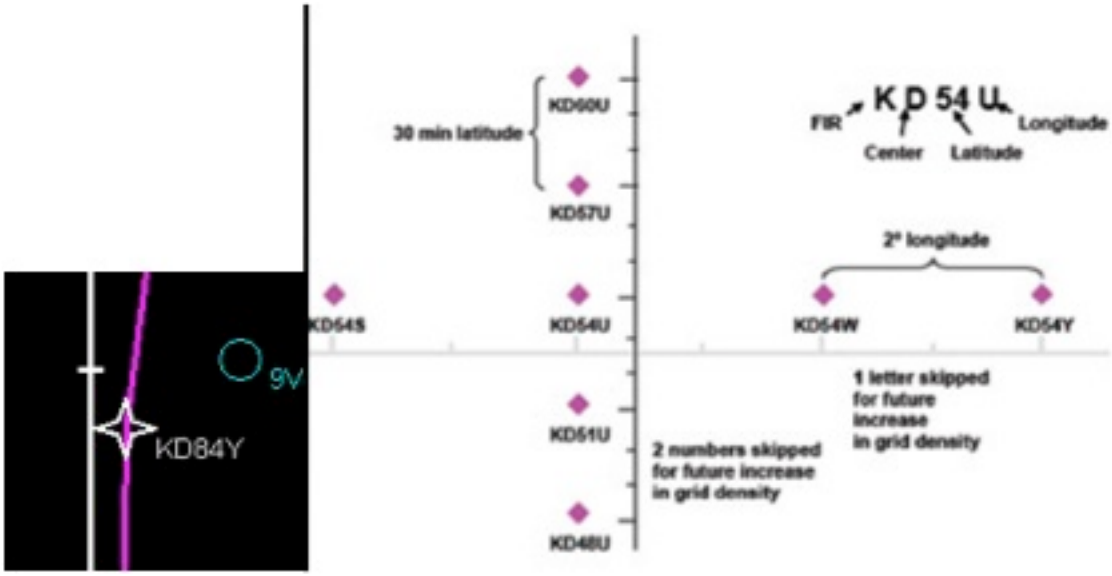

Rec 5 – Fig E. Example of an Offset Instruction.




Rec 5 -Fig F. Clearance and Graphics Illustrating a Simultaneous Operation and Two Sequential Operations.




Rec 5 - Figure G. Clearances and Graphics with Three Sequential Clearances.




Rec 5 -Figure H. Symbol and Labels of Waypoint NRS Nomenclature.

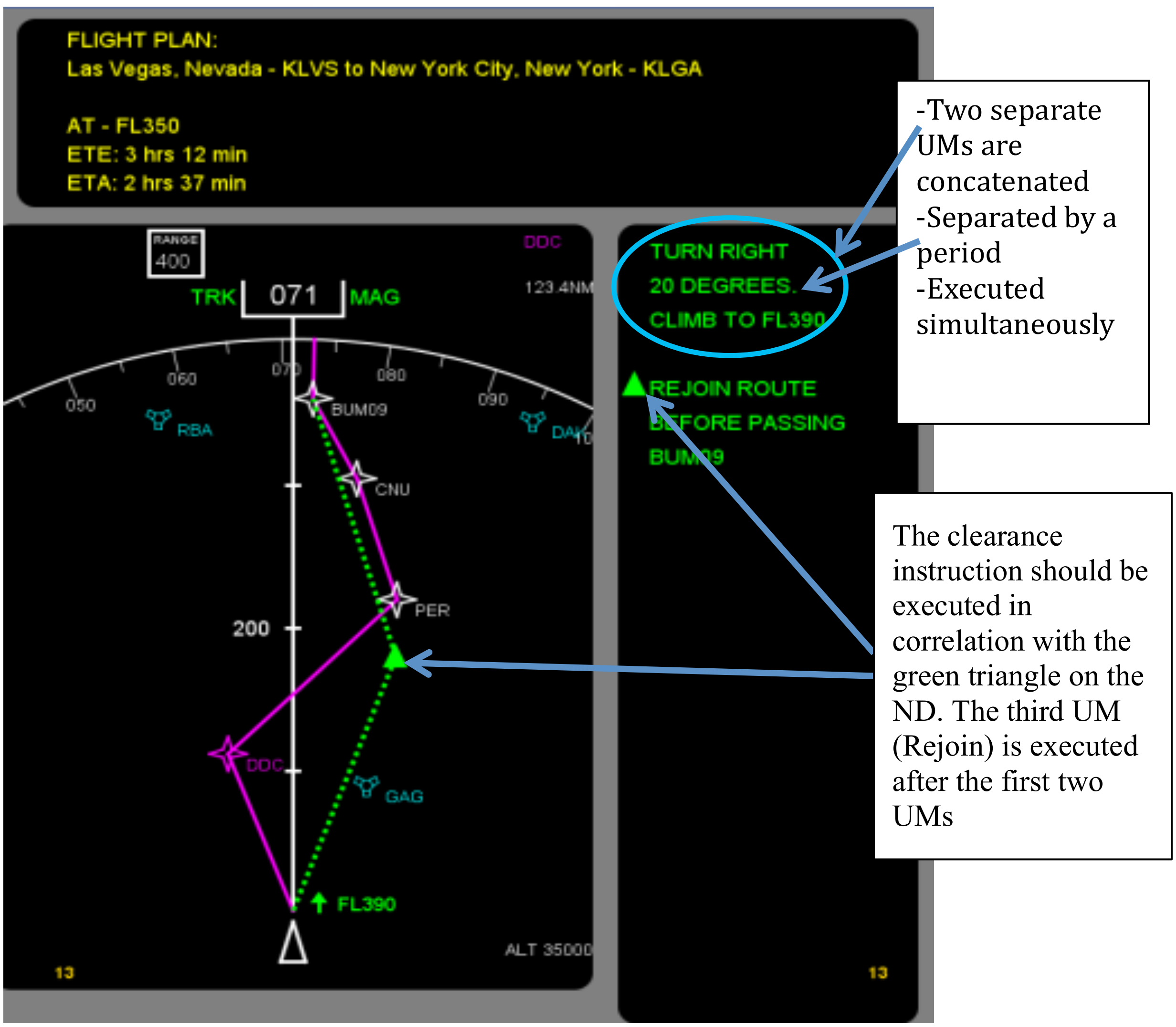
### 5.2.6. Distinguish Between Simultaneous versus Sequential UMs.

| Number 6 | Category: Graphic and Textual Display of UMs and DMs |
|---|---|

Title: Distinguish between simultaneous versus sequential UMs and DMS.

**Recommendation:** The graphic and text should clearly indicate simultaneous versus sequential operations.

**Rationale:** The pilot can act upon some concatenated UMs simultaneously. For example, climbing and changing heading can be acted upon simultaneously. However, others concatenated messages have a specific sequence. This is also true for DMs. Figure Rec 6-Fig A illustrates a concept for differentiating between the two types.




Rec 6–Fig A. Example of Text Layout and Symbols to Distinguish Between Simultaneous and Sequential UMs.

### 5.2.7. Symbols and Labels

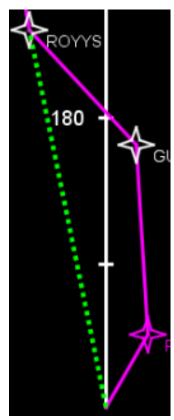
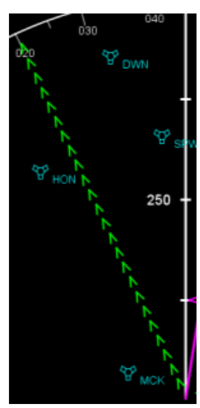
| Number 7 | Category: Graphic and Textual Display of UMs and DMs |
|---|---|

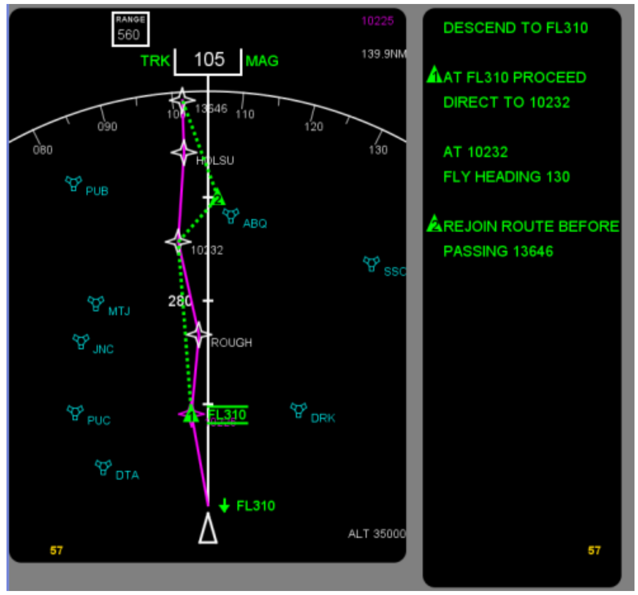
Title: Symbols and Labels

**Recommendation**: When using symbols and labels for UM/DM graphics on existing aircraft map displays (e.g. navigation display) or when designing new standalone graphic map displays for DataComm, designers should use existing guidelines and recommendations including RTCA D0-257A "Minimal Operational Performance Standards for the Depiction of Navigational Information on Electronic Maps" and AC 25-11.

**Rationale**: Existing standards based on research and currently in use by the FAA for certification must be followed. Utilizing existing standards and designs support more rapid learning by pilots.

Examples symbols and their meaning for different UM/DM elements and/or instructions

| Element | Meaning | Graphic |
|---|---|---|
| Triangle | Starting point of a clearance. |  |
| Dotted Line | The new flight path.<br>Green- Cleared by ATC<br>Orange- Requested by pilot. |  |
| Caret Line | Signifies heading change. (This provides heading not route)<br>Green – Cleared by ATC<br>Orange – Requested by pilot |  |

| | | |
|---|---|---|
| Number inside Triangle | Number signifies sequence to execute clearance. To be used for sequential clearances and conditional clearances or pilot requests. |  |
| Label Next to Triangle | Signifies flight level in clearance. Two lines signify maintain flight level. |  |
| Arrow Next to Label | Down arrow, begin descent to designated flight level.<br>Up arrow begin climb to designated flight level. | <br> |
| Line below flight level label | Must be at or above the specified flight level. |  |
| Line above flight level label | Must be at or below the specified flight level. |  |

### 5.2.8. Text and Graphics Placement on the Display

| Number 8 | Category: Graphic and Textual Display of UMs and DMs |
|---|---|
| Title: Distance between text and graphic UMs DMs | |
| **Recommendation**: The separation between textual UM DM information and graphic illustrations of UM and DM should be as close together as possible. The maximum distance should require only eye movements between the graphic and text if possible. If more separation is needed, the text should still be within the pilot and co-pilot primary viewing areas. | |
| **Rationale:** 1) To reduce the need for excessive head movement to crosscheck graphics and text. 2) To reduce head down time.<br>Research indicated that pilots want to be able to crosscheck graphics and text. Pilots had different strategies with respect to checking graphics on text first. | |

### 5.2.9. Display Permanence

| | | |
|---|---|---|
| Number 9 | Category: UMs and DMs | |
| Title: Display Permanence | | |
| **Recommendation:** The display illustrating UMs and DMs should always be visible to the pilot and co-pilot. | | |
| **Rationale:** Maintaining communication with ATC at all times is a priority for safety. Requiring pilots to change modes to view ATC messaging may result in missed messages and increased use of voice. Audio indicators or visual indicators of a received message may be missed depending on pilot attention. Even with the use of audio or visual indicators elsewhere in the cockpit the DataComm display should always be visible. The display is more likely to become integrated into the pilots scan pattern. | | |

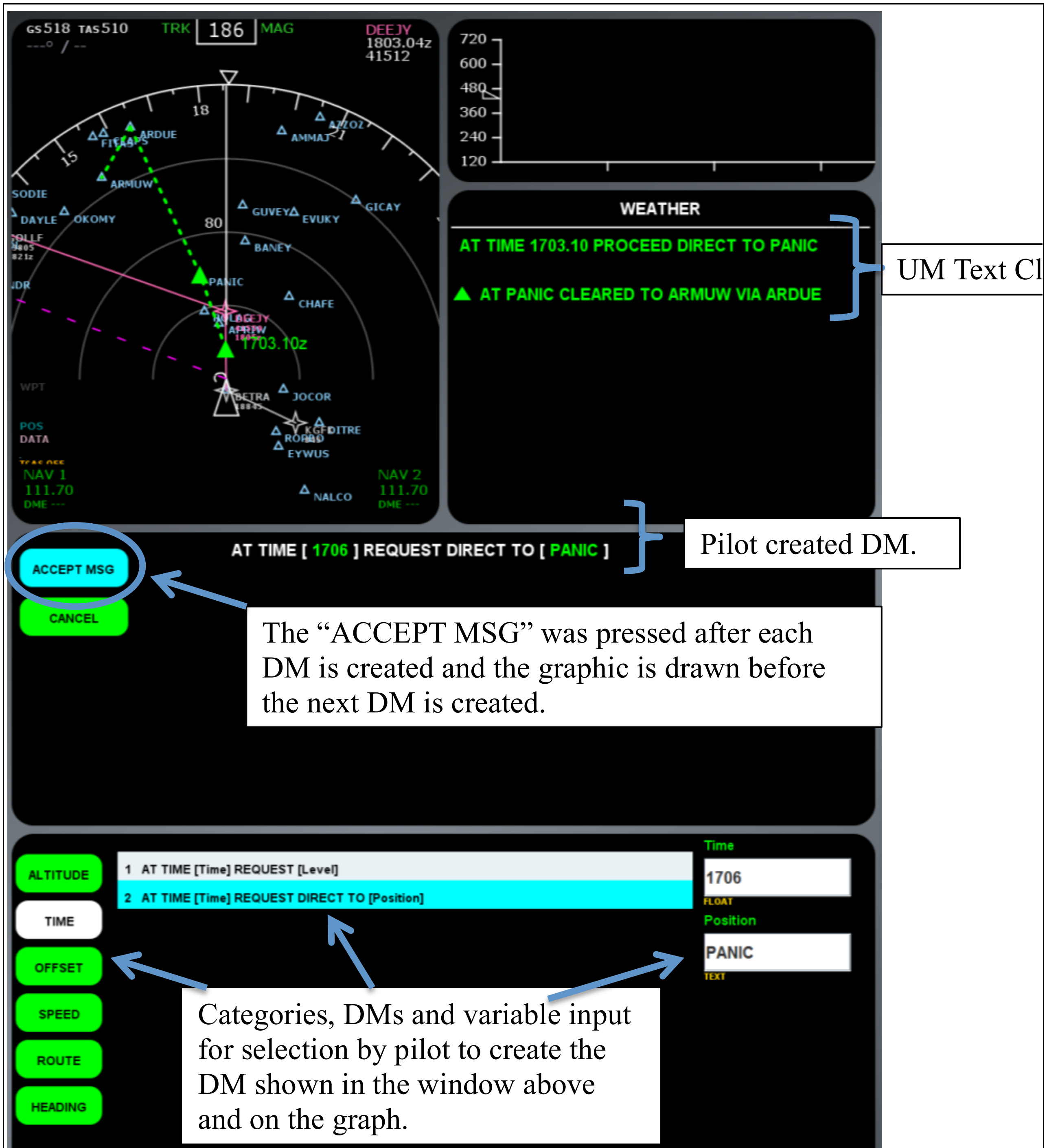
### 5.2.10. Current Setting of Range Level for DataComm Graphic Displays

| Number 10 | Category: Graphic and Textual Display of UMs and DMs |
|---|---|
| Title: Current Setting of Range Level for DataComm Graphic Displays | |
| **Recommendation:** Based on previous recommendations for electronic map displays, the user is able to select the map range (how much is visible). If a new UM appears, the range of the display may not be at the correct setting to view the UM graphic appropriately. However, changing the range automatically may confuse the user. The range of the DataComm display should remain at the last setting that the user applied. | |
| **Rationale:** Displays that change on their own automatically can cause user disorientation. The user must adjust the range to the appropriate positing for the UM or DM. | |

### 5.3. UMs and DMs

#### 5.3.1. Creating DMs

| Number 11 | Category: UMs and DMs |
|---|---|
| Title: Creating DMs | |
| **Recommendation**: The interaction technique in which the pilot can create downlink messages should allow the pilot to create the messages as quickly and easily as possible, with the fewest errors. | |
| **Rationale**: During one experiment (Exp 2) pilots noted that they had to provide too many inputs to create a concatenated DM. The specific method was to select a DM category, select the DM, and then input the variable (See Rec 11-Fig A below). They then selected an "ACCEPT MSG" button before moving on to the next concatenated DM. At times pilots forgot to press "ACCEPT MSG" after creating a section of the DM resulting in errors and repeated input. Pilots suggested that they create the entire message and press accept when completed. They then could review their DM and select "Send". Because of the large number of possible DMs, an interface must be simple and allow the fewest inputs possible. | |




Rec 11 – Fig A Graphic Illustrating How to Create a Concatenated DM Once a Clearance is Rejected.

### 5.3.2. Reviewing DMs

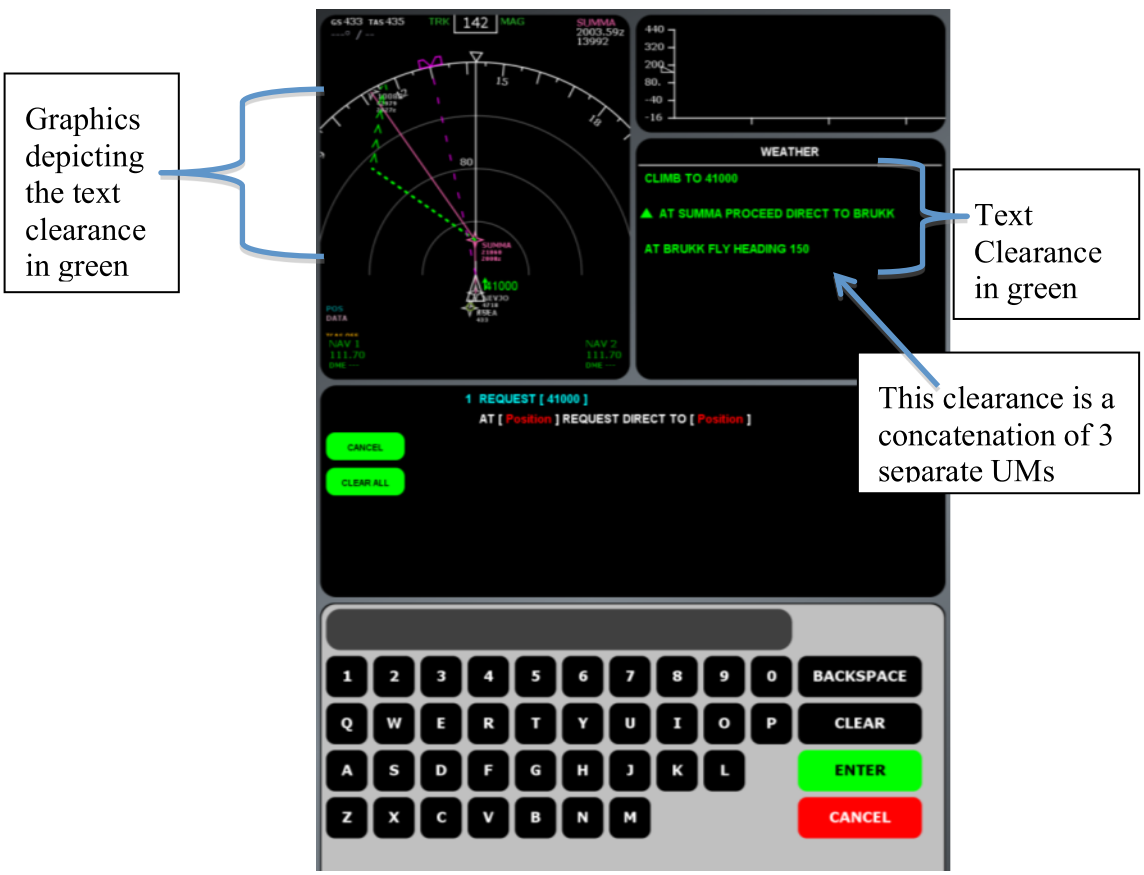
| Number 12 | Category: UMs and DMs |
|---|---|
| Title: Review DMs During Creation | |

**Recommendation**: The opportunity to review the downlink message as both graphics and text should be provided during DM creation and before the pilot "sends" the DM to ATC.

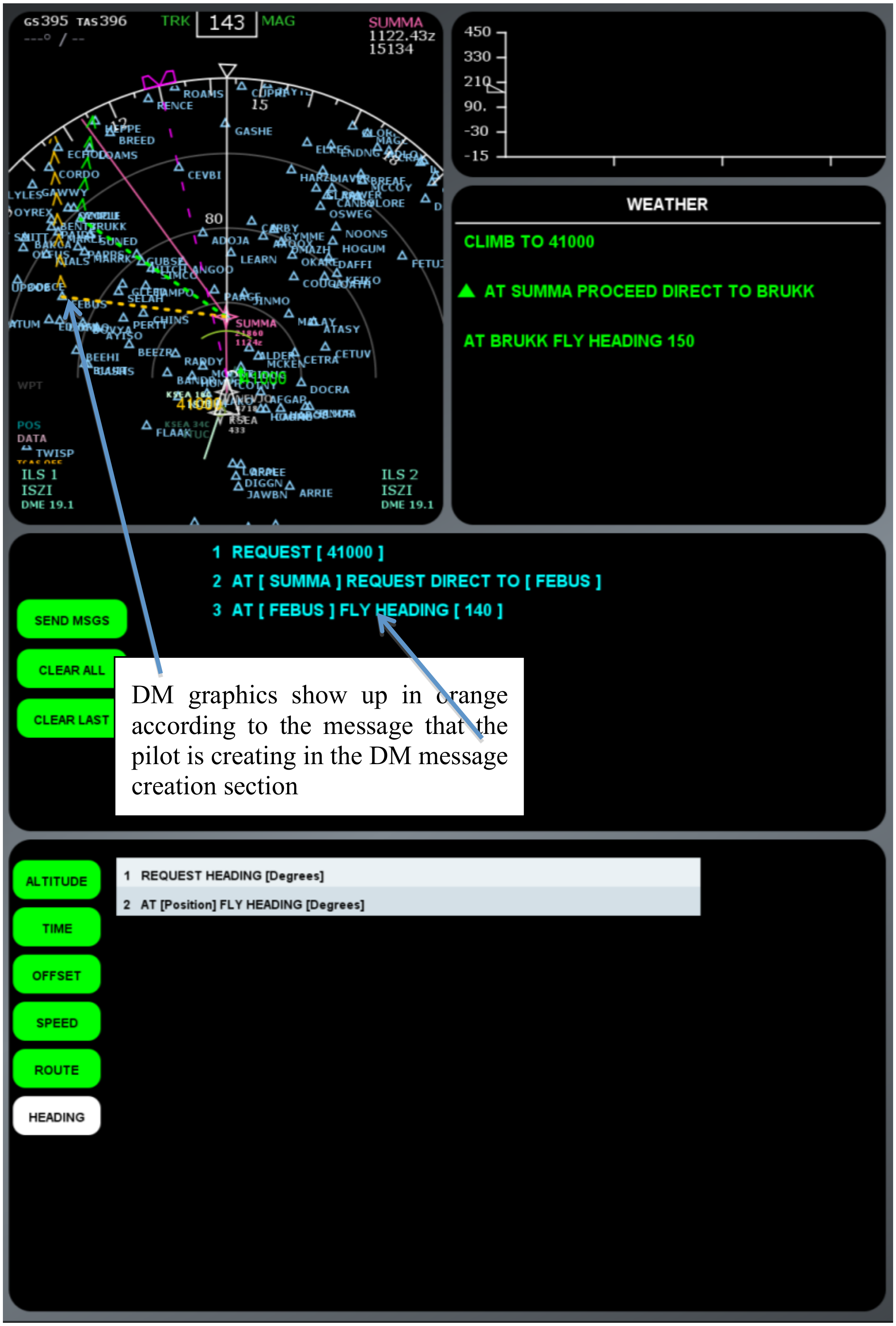
**Rationale**: As the pilot creates DMs the system should build a graphic representation of the DM. It is recommended that the graphic be created as each DM is added when messages are being concatenated. However, as discussed in recommendation 11, if the software requires an input after each DM in order to create the graphic this adds too many pilot inputs and is not recommended.

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 redundancy.

Rec 12-Fig A and B provide example illustrations 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 element.

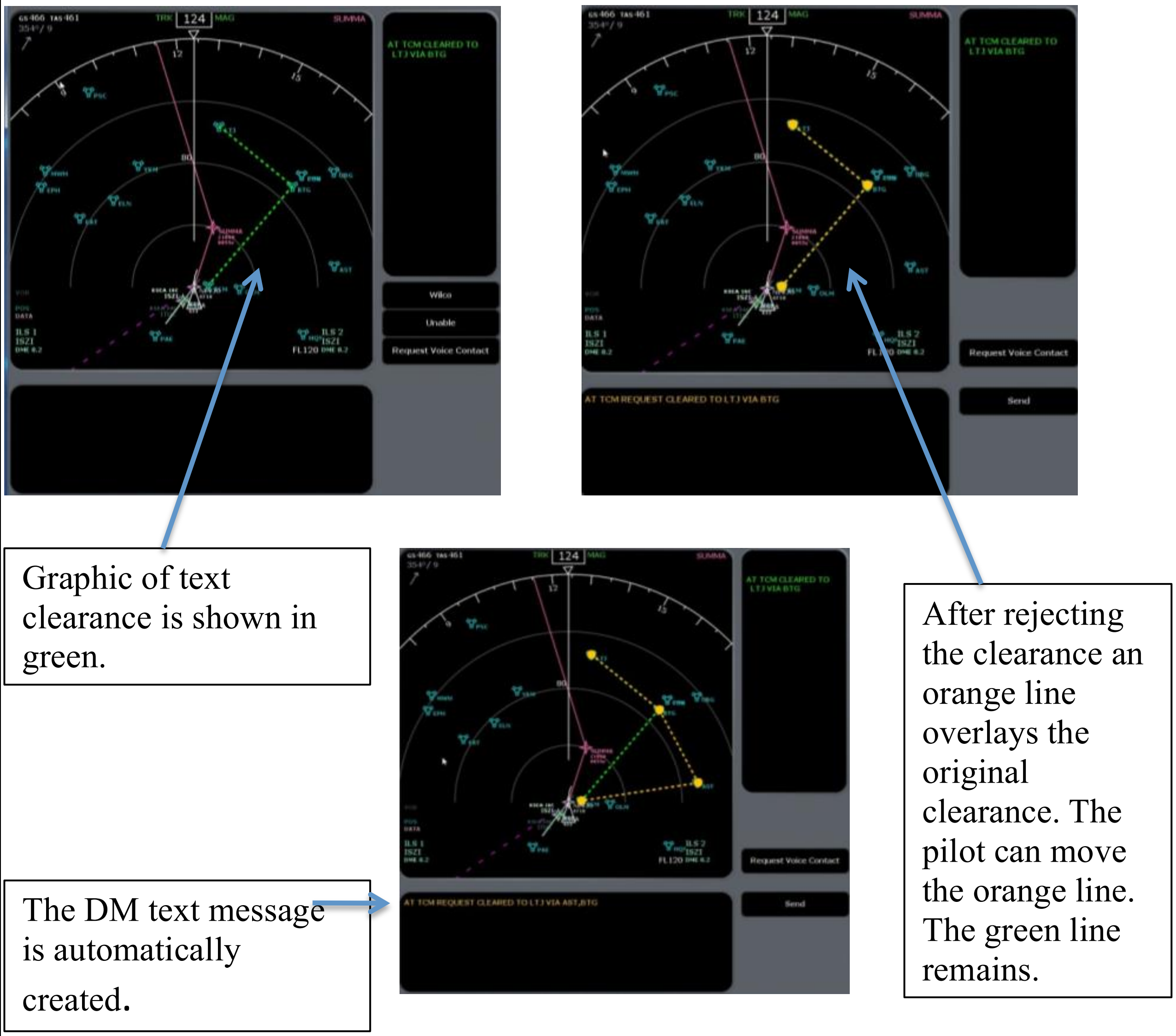



Rec 12-Fig A. Graphic Display With DM being Created. A Soft Keyboard is Use to Type in Variables Such as Position.




Rec 12 – Fig B. An Orange Line is Drawn in the Graphic Representing the Pilot DM Request.

Rec 12-Fig C illustrates an alternative graphic interface. With this interface the pilot first decides whether to accept or reject the clearance ("WILCO" or "ACCEPT"). The magenta line illustrates the original flight path and the clearance is illustrated in green. After a "REJECT" a new line is drawn in orange directly over the green clearance line and the original UM text is listed in the window below the graphic. The pilot can grab the orange line and move it to a desired position on the graphic display. The green clearance line always remains so they can see the original clearance graphically. As the route is altered the text DM is automatically created below the graphic display. The system selects the nearest waypoint or VOR name when the user releases the cursor. The DM is not sent until the pilot approves the final created DM. (Note: In this case the cursor was controlled using a finger on a touch screen display).




Rec 12-Fig C. Example of a Drag and Drop Interface to Create the DM Request.

### 5.3.3. UM Visibility After Pilot Decision

| | |
|---|---|
| Number 13 | Category: UMs and DMs |
| Title: UM visibility after pilot decision. | |
| **Recommendation**: The graphic and textual UMs should remain visible after a pilot decision (WILCO/Unable) until the pilot makes an action to clear the clearance. Once the decision is made there should be a visible indication of the decision selected. Examples include removing or graying the WILCO/Unable selection or making a change in how the text or graphic UM is displayed. | |
| **Rationale**: If a pilot accepts (WILCO) a UM, they must still carry out the clearance either by inserting the information into the FMS or through another action. If the UM is rejected, it must remain visible in order to allow the pilot to negotiate the clearance with ATC. AC 20-140A also indicates the pilot should clear the message. | |

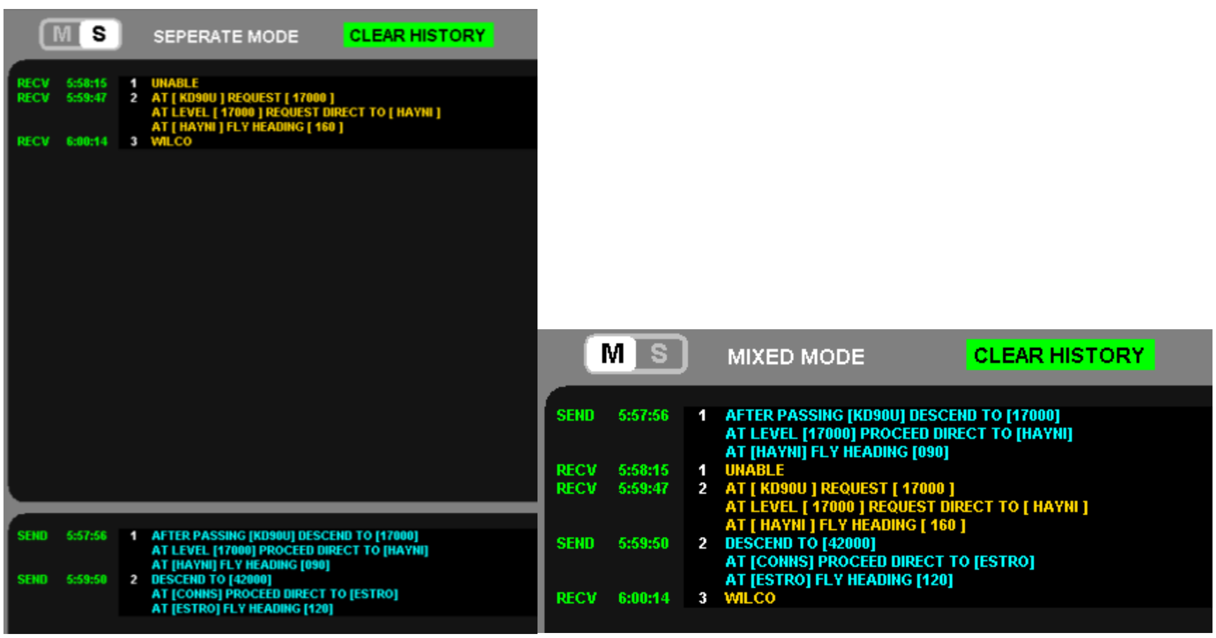
### 5.3.4. UM/DM History Logging

| Number 14 | Category: UMs and DMs |
|---|---|
| Title: Logging UMs and DMs | |

**Recommendation**: After a pilot clears the DataComm message display the UM and DMs should be moved to a text log with the most recent UM/DM displayed first. The text log should include the message and time stamp.

**Rationale**: All pilots indicated they needed to have a history of their interactions with ATC for reference. AC 20-140A also recommends logging UMs and DMs.

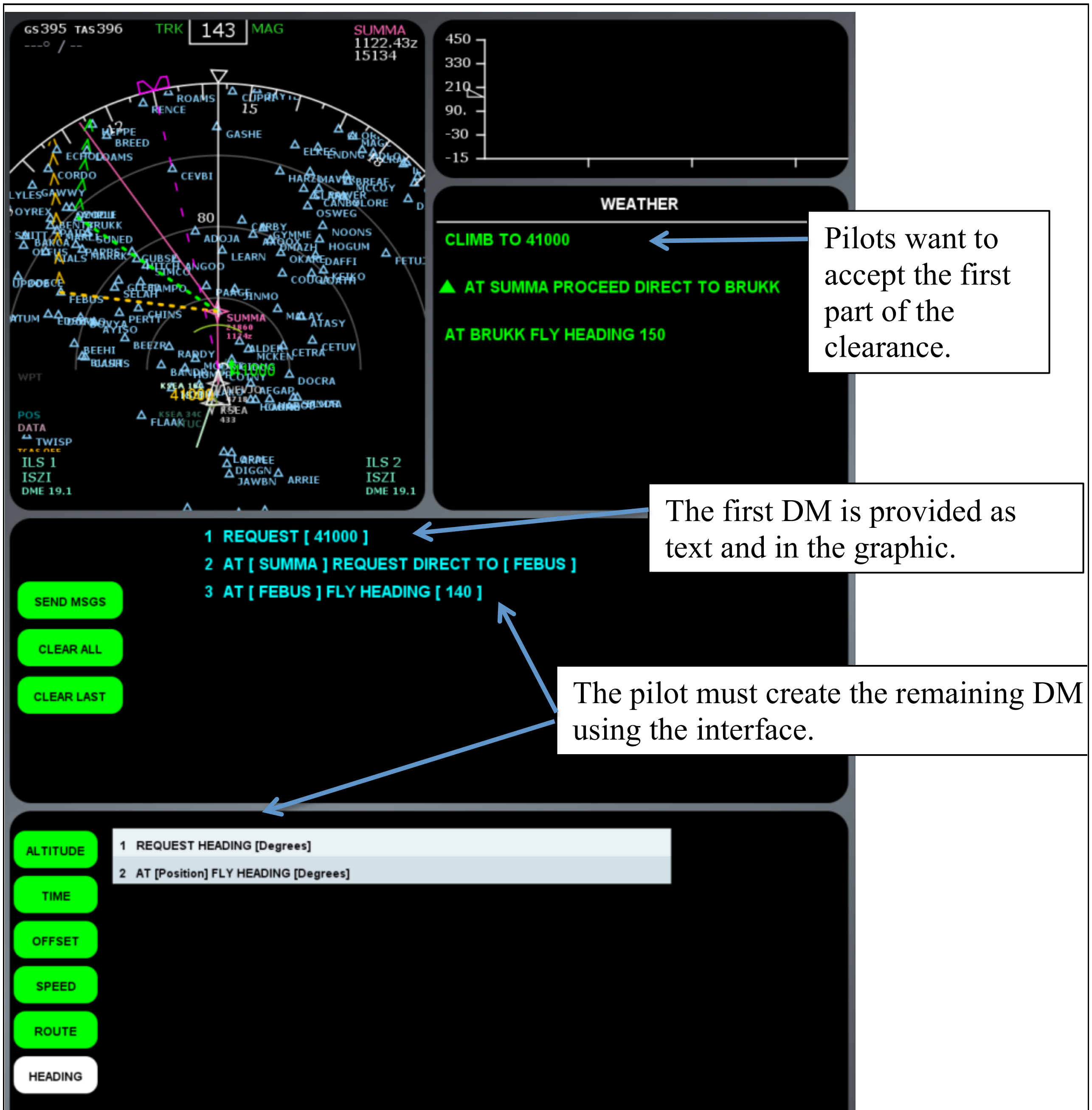
It is suggested that the pilot be provided with two choices for viewing the log. One is in separable mode where the ATC messages are in one window and pilot responses in a separate window. The second option is a mixed mode showing the messages in the order of occurrence to illustrate the "conversation". Rec 14-Fig A illustrates this concept. The pilot would only need to make one input to switch the mode.




Rec 14-Fig A. Example of Separate and Mixed Mode Viewing of DataComm Communications Log.

### 5.3.5. Partial Clearances

<table>
<tr><td>Number 15</td><td>Category: UMs and DMs</td></tr>
<tr><td colspan="2">Title: Accepting Partial Clearances.</td></tr>
<tr><td colspan="2">Recommendation: This research did not evaluate the ability to accept part of a UM clearance. Most pilots commented on this saying that if only part of a clearance was unacceptable there should be a way to accept part of the clearance and create DMs only for the part that is rejected. It is recommended that clearances should be rejected in their entirety or there may be time delays or misunderstanding with ATC. To support timely interaction with ATC through DM messages, the recommendation is to support the pilot by allowing portions of the message that are acceptable to be marked as acceptable by the pilot. Then those marked acceptable would be automatically created as a DM so the pilot only has to create DMs for part of the clearance.</td></tr>
<tr><td colspan="2">Rationale: Enabling the concept of partial clearances for the pilot is a matter of providing the portion of the message that is acceptable back to the pilot in a ready to send format. Then allow them to create the DM for the portion that they are rejecting. The pilot could be provided with the ability to mark the part of the concatenated UMs to keep and UMs to change. The DM(s) is then presented to the pilot in text and graphics that are ready to send. The pilot adds the DM(s) that require a change. This would reduce the number of inputs to create DMs. Two possible error outcomes that should be considered are:<br>1) When having to reconstruct the entire UM there is a possibility of input error that could be reduced if part of the message was marked as acceptable. (Pilots made input errors during experimentation, often having to start over).<br>2) Recreating the entire message, even though parts are correct, may help pilots to better understand the message before it is sent. This may reduce errors for complex clearances.<br>Figure Rec 15 Fig A. illustrates the concept based on the displays used during experimentation.</td></tr>
</table>




Rec 15-Fig A. Example of Partial DM Created After Part of UM is Acceptable.

#### 5.3.6. Support Routine DM Selection

| Number 16 | Category: UMs and DMs |
| --- | --- |
| Title: Support routine DM creation | |
| **Recommendation**: There may be cases where concatenated DMs become routine or used often. In this case it should be possible to create an icon or other interface technique that allows pilots to select the routine DM without being required to go through multiple steps for selecting the message and inputting the variable. This reduces input to two selections: selection of the routine DM and, after evaluation via text and graphics, sending the DM to ATC. | |
| **Rationale**:<br>Given the large number of possible DMs and the concatenation of DMs, the creation of routine DMs should be available to save time and reduce error. | |

### 5.3.7. Time for creating and sending DMs

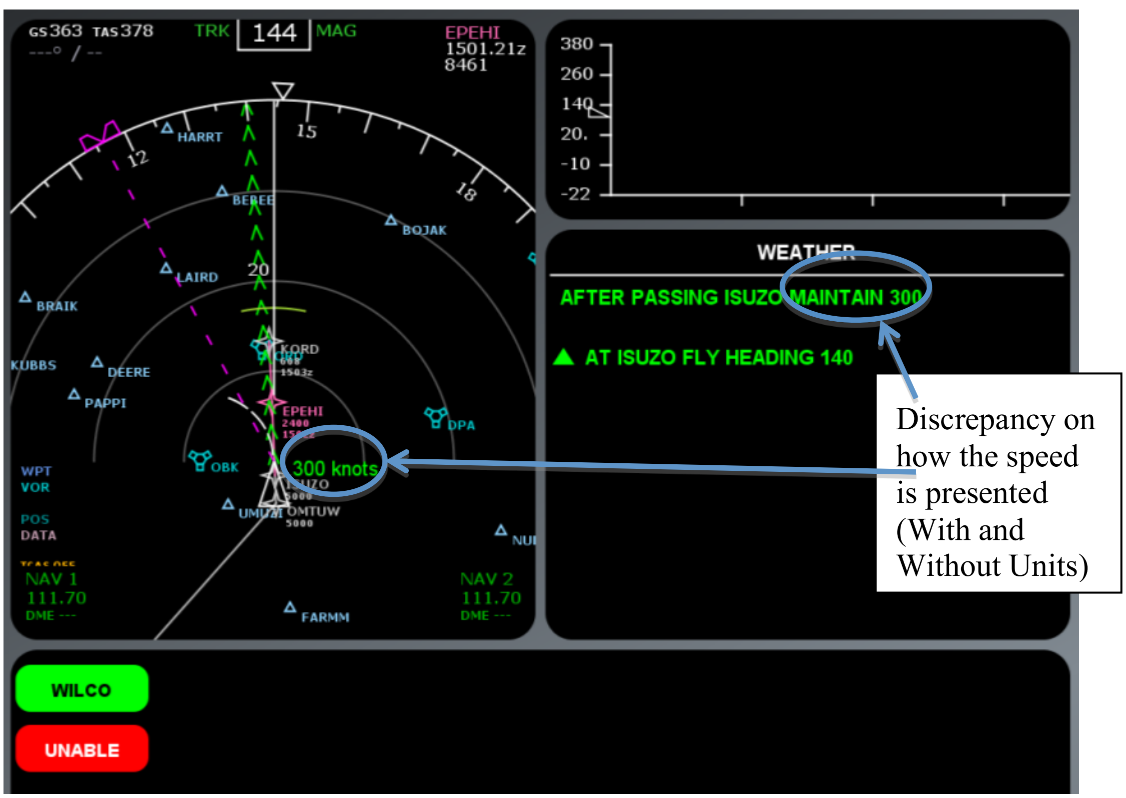
| | |
|---|---|
| Number 17 | Category: UMs and DMS |
| Title: Timing for sending UM clearances | |
| **Recommendation:** For non-emergency communication, ATC must take into consideration the time necessary to negotiate a concatenated UM through creation of DMs. When a pilot sends a "Reject/Unable", it will take time to create a DM and the amount of time depends on the dynamic complexities within the flight deck in a real life situation. Therefore it is necessary to determine minimum values for sending UMs based on 1) the distance to a waypoint where the cleared action is required to occur or 2) the minimum time before a clearance is to be initiated. | |
| **Rationale**: If the UM is rejected and a DM must be composed, the ability to create the DM must be within the distance or time frame for when the action will be carried out. If the pilot passes the waypoint in the original UM, or the specified time has passed, the negotiation becomes more complex is now irrelevant because the information in the original clearance is out of date. | |

### 5.3.8. UM and DM Units of Measure

| Number 18 | Category: UMs and DMS |
|---|---|
| Title: UM and DM Units of Measure | |

**Recommendation**: Consider specifying units for some textual UMs to clarify meaning. E.G. UM 310: After passing [Position] maintain [Speed]. When the position variable is given, it is understood to be a position whereas when a speed variable is given (i.e. 300) there is confusion as to whether it is an altitude or speed.

**Rationale**: Most UMs and DMs do not specify the units of measure because they are considered to be part of the text. For example, UM 310: After passing [position] maintain [speed]. Pilots did not necessarily know that 300 meant 300 Knots (although it specifically stated 'knots' on the graphic navigation display). When they try to create a DM to change this value there was a misunderstanding of the unit, thus pilots choose a category for the DM unrelated to speed. The DM message becomes irrelevant at this point. Many pilots assumed 300 was an altitude, referring to a specific flight level. An example of this DM is presented in Rec Fig 18 A.



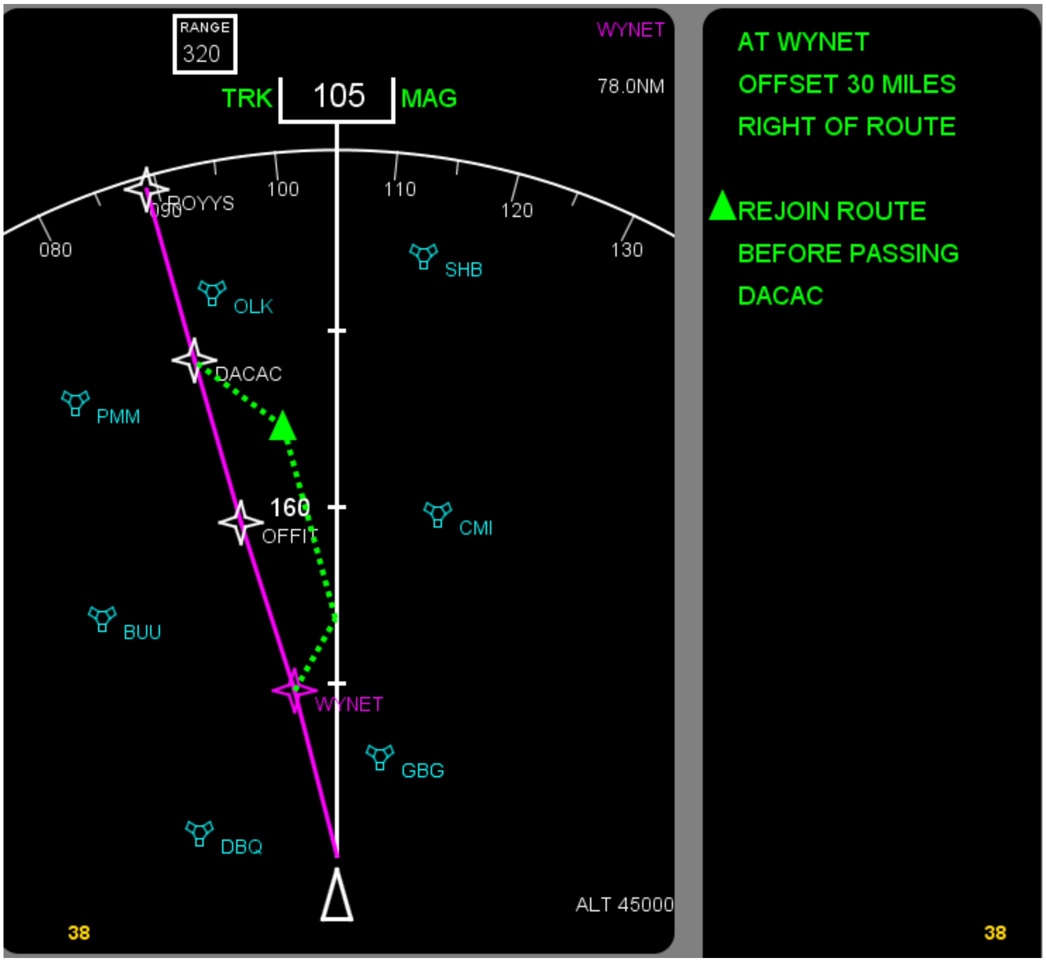

Rec 18-Fig A. UMs that do not specify units of measure.

### 5.3.9. Drawing Graphic DMs Regardless of Concatenation Order

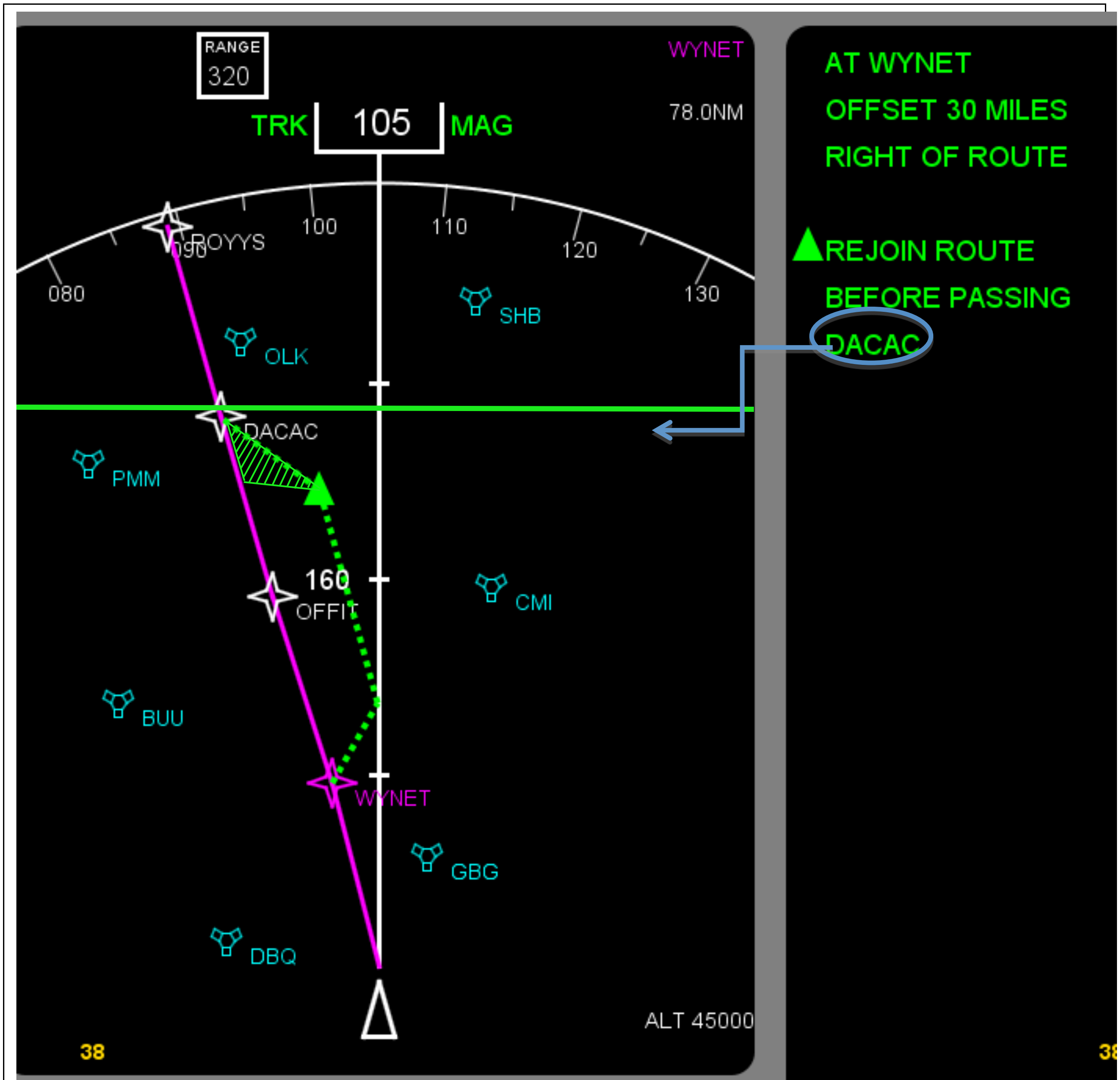
| Number 19 | Category: UMs and DMs |
| --- | --- |
| Title: Drawing Graphic DMs regardless of concatenation order. | |
| **Recommendation**: When pilots are concatenating DMs they may concatenate the messages in any order. Regardless of the order of the concatenated DMs, the graphic should be drawn correctly. | |
| **Rationale**: During experimentation some pilots noted that part of their DM did not register when they thought they had provided the input. (They forgot to "ACCEPT MSG"). Two pilot strategies were noted. Some pilots would clear the DMs and start from the beginning following the order of the UM. Others would just add the missing DM on at the end. Regardless of order, the graphic should be drawn correctly. | |

### 5.3.10. Rejoin Route Graphics

| Number: 20 | Category: UMs and DMs |
|---|---|
| Title: Rejoin Route Graphics | |
| **Recommendation:** If the intended meaning of this UM is to allow pilots to rejoin the route at their discretion as long as it is before the POSITION, then a single green horizontal line at POSITION is effective at providing the limit by which they must rejoin.<br>However, technically this would allow the pilot to rejoin as soon as 30 seconds and still be in compliance with the textual UM.<br>If the intention of the UM is more specific as to when to begin the rejoin after an offset, than a green horizontal line with a shaded region indicating the zone in which they may rejoin reduces ambiguity. | |
| **Rationale:** The first graphic created and tested to visualize UMs related to Rejoin Route Before Passing [position] is illustrated in Rec 20-Fig A. This graphic provided an indication of where to begin the rejoin. The graphic and text were both problematic for pilots. Rejoin Route UMs had the most errors and longest response times presented as text and graphics. Pilots stated they thought that the graphics were inconsistent with the textual UM. Pilots indicated that typically they rejoin at their discretion and prefer to rejoin immediately. Therefore they were concerned that the statement BEFORE PASSING allowed them to rejoin at any point, and that this might allow too much discretion that would not match the intention of when to rejoin intended by ATC. In other words, technically they could rejoin 30 seconds after they were offset and comply with the textual UM (although not the graphic depiction).<br>In subsequent testing a green horizontal line was placed directly through the POSTION specified in the clearance. This provides a very clear definitive clearance limit of that position that is very salient. This graphic should be used if the intention is to let the pilot rejoin whenever they want.<br>A better approach to help alleviate ambiguity related to this UM is to add a green triangular shaded graphic between the horizontal green line and the position in which the earliest rejoin can begin as illustrated in Rec 20-Fig B. The pilots may rejoin at their discretion within the bounded zone provided by the graphic | |



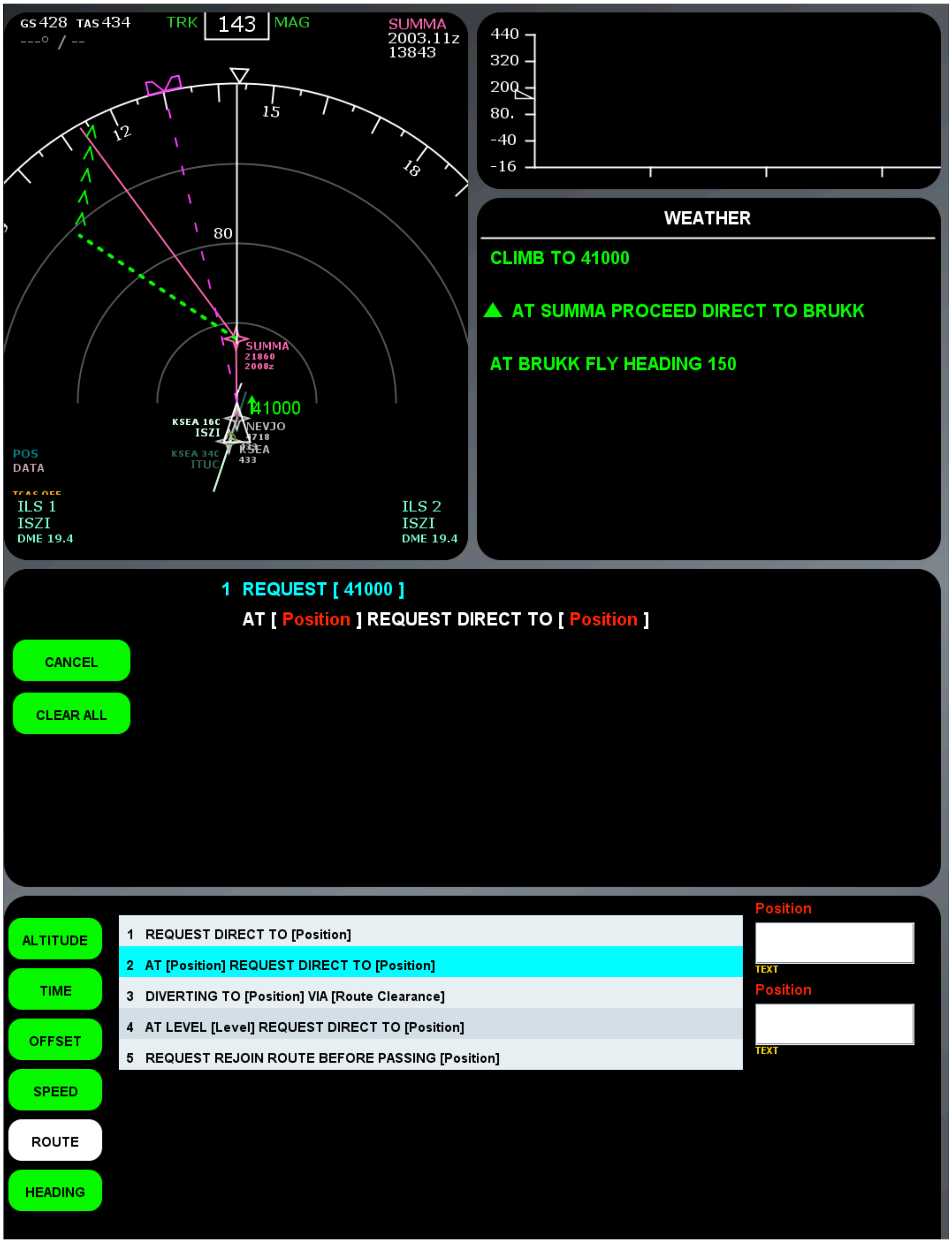

Rec 20-Fig A. Example of a Graphic to Indicate Where to Begin a Rejoin. This Graphic Was Problematic for Pilots.




Rec 20 –Fig A. Graphic with Shaded Region to Indicate Earliest Position to Rejoin and Green Line to Indicate Position at Which Rejoin Must Be Complete.

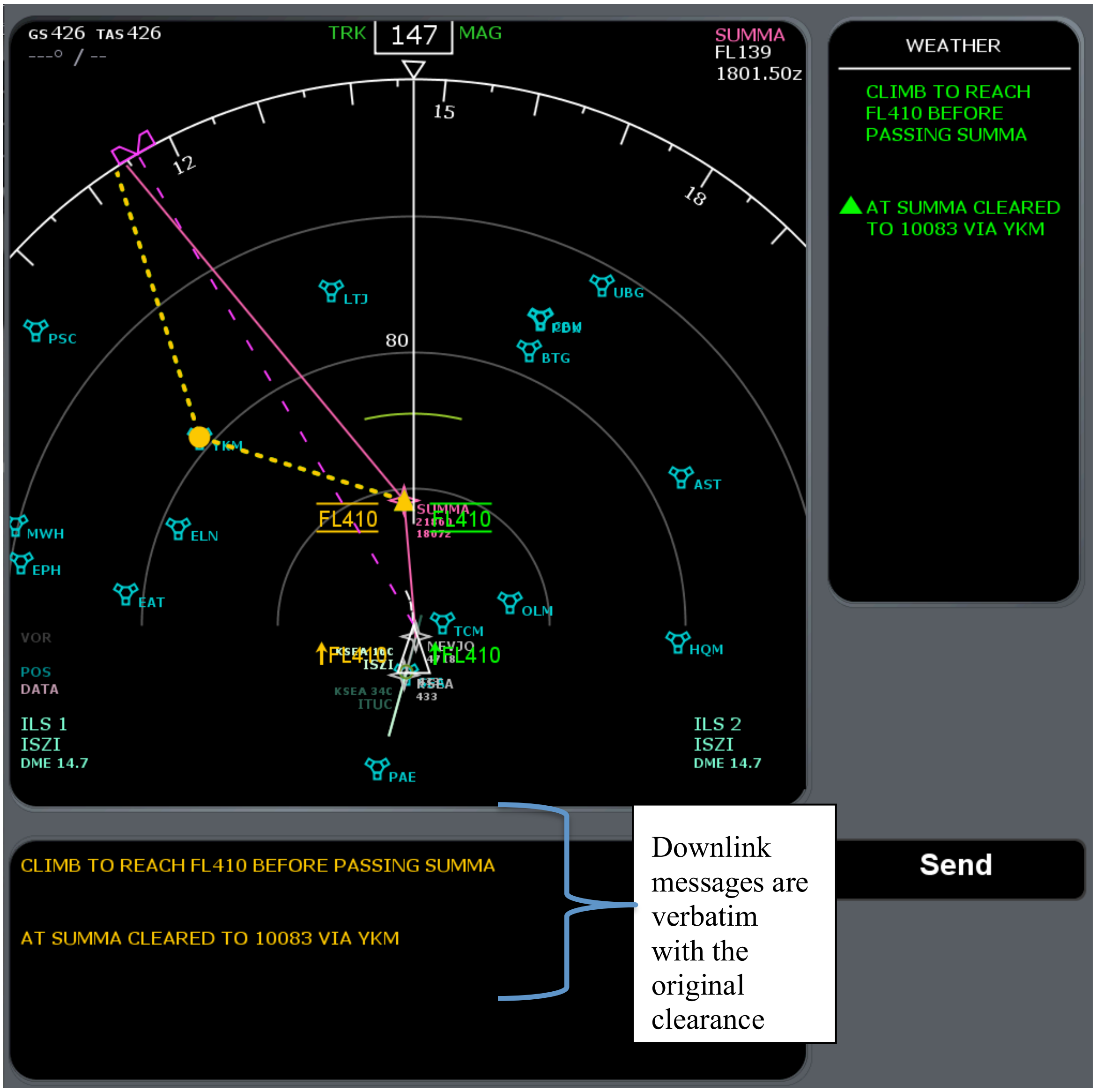
### 5.3.11. Responding to a Clearance

| Number 21 | Category: UMs and DMs |
|---|---|
| Title: Responding to a Clearance | |
| **Recommendation:** The display should provide pilots with a text and graphic downlink message that repeats the clearance verbatim once the pilot "Rejects" a clearance. This allows the pilot to directly edit the clearance to create the DM. As they edit the DM they can see how it changes from the original clearance. | |
| **Rationale:** Two different user interfaces were evaluated for creation of DMs when responding to a clearance: Textual Creation and Graphic Creation. Both are briefly described below, followed by the rationale for the recommendation.<br><br>Interface 1: Textual Creation (TextGEN)<br><br>With this interface pilots reviewed the clearance and were required to create a DM by choosing a category via buttons on the display. The display changed to list the DMs for that category. Once they chose the DM they would then enter the variable value for the DM. (See Ref 21-Fig A below). The text and graphic DM would be presented as they were building the message. In other words, the original clearance UMs were not available for immediate editing.<br><br>Interface 2: Graphic Creation/Manipulation (GraphicGEN)<br><br>With this interface (Ref 21-Fig B - D) a second graphic copy of the clearance is directly overlaid on the green original clearance using a second color (orange). The DM is also provided as text as an exact replica of the original clearance, also in the second color. The user can touch the graphic on the ND and move the orange graphic to another location. They can also select a variable on the graphic and a keyboard is presented allowing them to edit a variable value (such as altitude). As they change the graphics on the ND, the text DM is updated automatically in the window below. | |

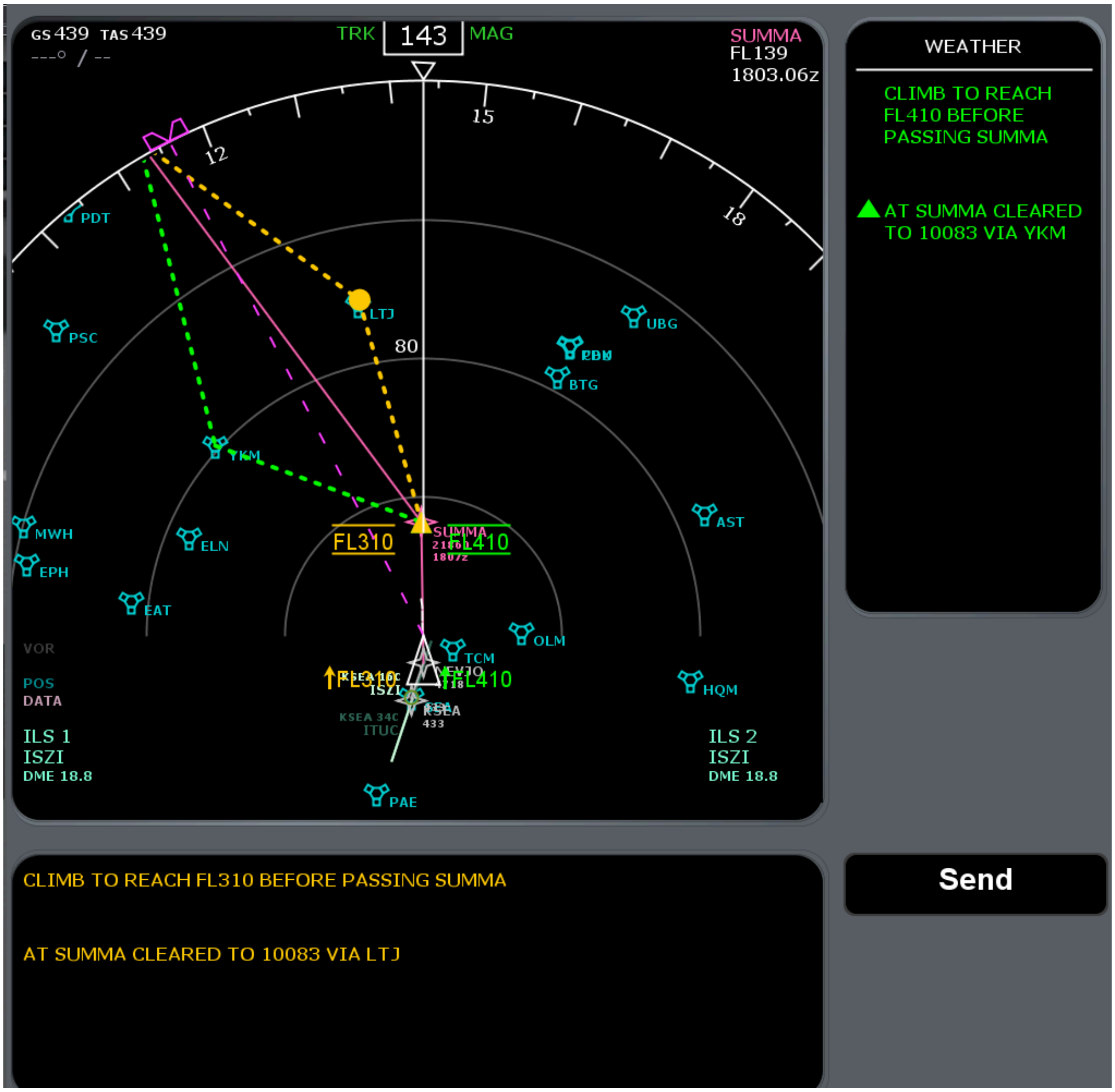



Rec 21-Fig A. Textual creation of DMs.


Rec 21-Fig B. Step 1: Pilot Choses Unable




Rec 21-Fig C. Step 2: DM Graphic Created. The DM graphic is overlaid on top of the original clearance. The DM text is a copy of the original clearance.

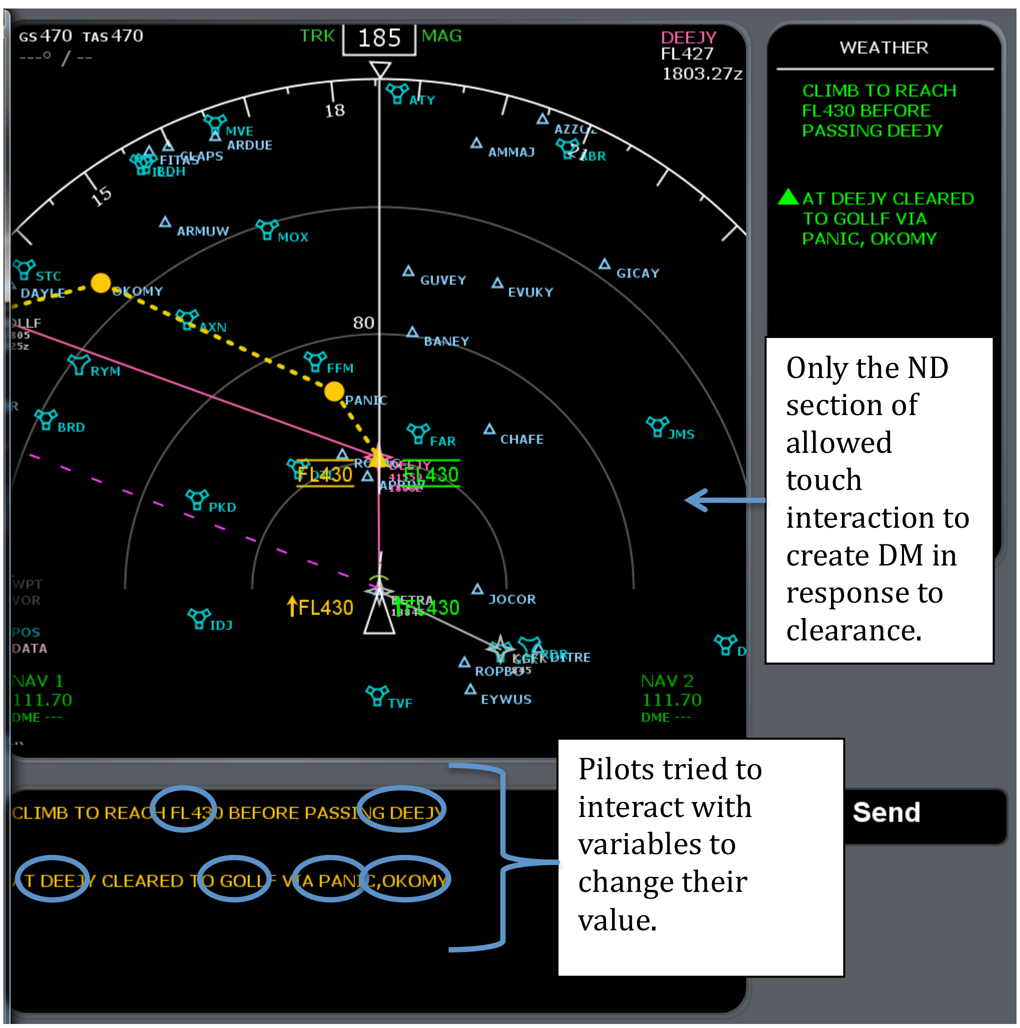



Rec 21- Fig D. Step 3. Manipulate Graphic. As the pilot manipulates the graphic (e.g. FL edit and change in flight path), the text automatically changes to match the graphic. The pilot can review both to ensure a match before sending.

The second interface helped to reduce some errors. For example in the Textual Creation interface, the DM text clearance "At [POSITION] Request [LEVEL]" was sometimes confused with "At [LEVEL] Proceed Direct to [POSITION]". Pilots would incorrectly select the second message instead of the first message. Then they spent time editing the values when the DM was irrelevant with respect to the clearance.

**5.3.12. Editing for DM Creation: Interaction with Text and Graphics.**

| Number 22 | Category: UMs and DMs |
| --- | --- |
| Title: Editing for DM Creation. Interaction with Text and Graphics | |
| **Recommendation:** To create a DM through editing a UM, the pilots should be able to interact with both the graphics on the ND as well as the text of the DM. | |
| **Rationale:** For the Graphic Creation Interface, pilots would edit the clearance using the graphics on the ND display after a response of Unable. The text under the graphic was presented and automatically updated as they manipulated the graphic. However, based on their experience with touch screen technologies, pilots expected to be able to touch a text variable and edit it (See Figure Ref 22-Fig A below). | |




Rec 22 – Fig A. Examples of Interactive Touch Screen. Allow users to interact directly with the message by placing a cursor on the variable to be edited.

**5.3.13. DM Variable Input. Allow selection of a waypoint or location on the ND to populate DM messages.**

| Number 23 | Category: UMs and DMs |
|---|---|
| Title: DM Variable Input. Allow selection of a waypoint or location on the ND to populate DM messages. | |
| **Recommendation:** During creation of a DM, the pilot should be able to use a cursor to select a location on the ND as input for position rather than type in the waypoint name or lat/long. | |
| **Rationale:** When pilots need to choose a new waypoint or change a waypoint specified in an original clearance it is faster and less error prone if they can select the waypoint rather than typing in names or lat/longs. In Experiment 3, pilots could move the cursor on the graphic and the nearest waypoint would be populated into the text message automatically. | |

### 5.3.14. Creating a DM without responding to a clearance.

| Number 24 | Category: UMs and DMs |
|---|---|
| Title Creating a DM without responding to a clearance. | |
| **Recommendation:** Pilots should be able to easily create a DM to make a request to ATC without having to respond to a clearance. | |
| **Rationale:** The two interaction techniques investigated, Text Creation and Graphic Creation were tested under the conditions of receiving a clearance. When a clearance is received the recommendations indicate that editing the clearance is the best choice. However, when pilots are creating a DM without first receiving an ATC clearance, they should still be able to use the same techniques to create a DM. That is, the interaction techniques should be consistent. | |

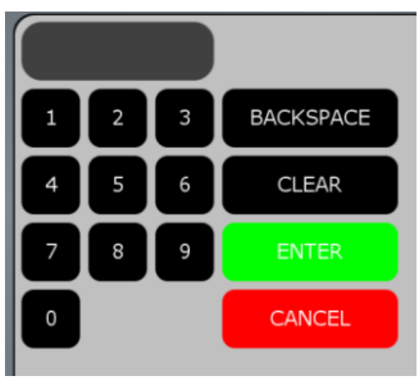
### 5.3.15. Error Prompting

| Number 25 | Category: UMs and DMs |
|---|---|
| Title: Error Prompting | |
| **Recommendation:** When waypoint names are spelled incorrectly or if the waypoint in the DM is not near the aircraft location, an error prompt should appear. | |
| **Rationale:** Pilots often misspelled waypoint names and did not always catch their mistakes. This is a common error in aviation and medicine. | |

## 5.4. INPUTS

### 5.4.1. Control the input type to only those needed for the current input situation.

| Number 26 | Category: Inputs |
|---|---|
| Title: Control the input type to only those needed for the current input situation. | |
| **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. Error checking should also be performed to identify unacceptable inputs. | |
| **Rationale**: Reducing the possibility of input errors supports human performance. Rec 26-Fig A illustrates softkey pads. The type of keypad available depends on the type of input. For example if a position variable is needed and waypoints only consist of letters, numbers would not be available. | |


Rec 26-Fig A. Example of Softkeys Used for Data Input on a Touch Screen.

### 5.4.2. Visibility of waypoints listed in a clearance. Zoom and Pan

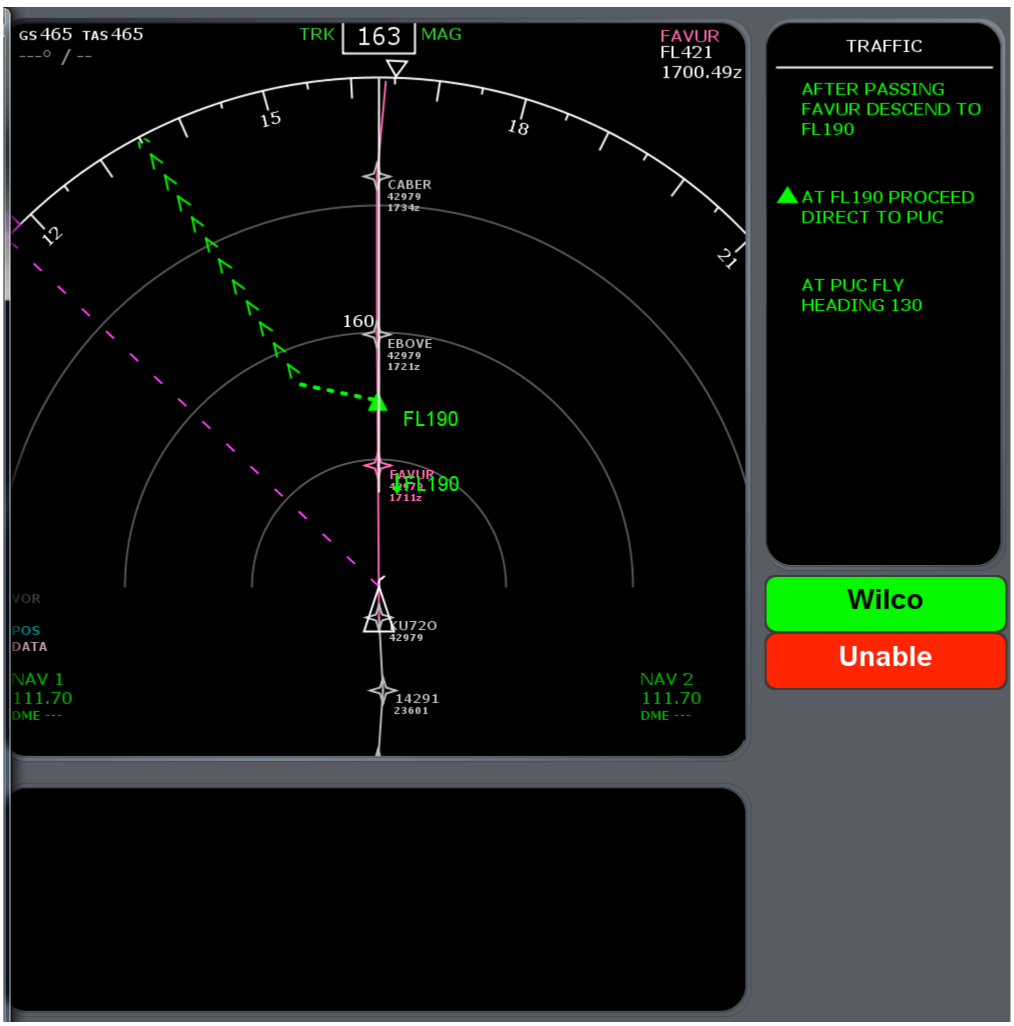
| Number 27 | Category: Inputs |
|---|---|

Title: Visibility of waypoints listed in a clearance. Zoom and Pan

**Recommendation:** The waypoint name(s) referenced in a clearance should always be visible on the ND regardless of the current ZOOM level. Alternatively, a technique to allow the pilot to zoom to the level that provides visibility of the entire clearance with just one input should be considered.

**Rationale:**

Figure Ref 27-Fig A illustrates a clearance where a waypoint specified in the clearance (PUC) is not visible because of the zoom level.




Rec 27-Fig A. The Waypoint PUC Referred to in the Clearance is not Visible at this Zoom Level.

| |
|---|
| The graphic indicates that the once the plane meets FL190 (Green Triangle) they need to Proceed Direct to a position, and then fly a heading. The pilots' first instinct is to confirm that the point referenced on the navigation display is actually 'PUC'. The pilot is required to manipulate the zoom level using the ND zoom rotary button. The feature of de-cluttering the display when zooming out is well accepted by pilots. However, pilots prefer the referenced point in the clearance to remain on the navigation display regardless of the zoom level. This recommendation would alleviate issues of ambiguity and reduce time to respond. |
| This recommendation should be considered with respect to whether the placement of the waypoint, given the zoom level, would be confusing as it would be relative and not specific.<br><br>A possible alternative would be to provide a single input (button) that would zoom the display to the position where all waypoints are visible.<br><br>In either case, for complex clearance re-routes placing all information on one graphic could be a problem. Panning capability may also be necessary. |

# 6. Appendix 2: Tool for Testing and Certifying the Effectiveness of Text and Alternative Flight Deck Display Format for ATC DataComm Messages

## 6.1. Introduction

Air-ground ATC Data Communications (DataComm) is a key technology that will come into broad use under NextGen. Beyond its promise to alleviate voice frequency congestion's contribution to capacity limits and reduce communications errors, DataComm is a common enabling technology for the implementation of NextGen automation solutions and collaborative control concepts. NextGen controllers and pilots will use DataComm not only to carry out routine ATC communications, but to conduct negotiations, communicate complex 4D clearances and trajectories, resolve anomalies, intervene in non-normal situations, coordinate expectations and intentions, and validate proposals made by automation systems.

Several classical flight deck configuration variables such as message display location and alerting will need to be addressed during the implementation of DataComm under NextGen. However, it is likely that two somewhat unique human factors issues will play particularly important roles in determining the extent to which this system succeeds in safely and efficiently supporting all of these potentially complex information exchange tasks. The first of these is the phrasing of new and modified forms of DataComm ATC text messages that are being developed for global use and will support NextGen operations in the NAS (RTCA, 2012). As these messages are proposed for implementation, efforts must be made to ensure that they are not difficult to understand, confusing or ambiguous. Specifically, when displayed to aircrew in text format, the wording of standardized clearances and other messages sent by ATC must be chosen to ensure that aircrew will be able to interpret and act on the intended content quickly and accurately. Aircrew must be confident that the aircraft's flight management system (FMS) will carry out any automatically loaded instructions derived from the ATC clearances as they were intended by the controller and interpreted on the flight deck.

The second issue comes into play as developers consider non-traditional alternatives to text displays for communicating complex routing instructions intended to guide the precise three and four dimensional aircraft trajectories that will be possible under NextGen. Proposed alternatives are likely to include graphical, symbolic and hybrid representations of clearance message content. At a minimum, scientifically sound steps must be taken to ensure that these display alternatives are at least as effective and accurate as text in transmitting clearance information to aircrew.

To address both of these issues, system designers and certification specialists must have a means to ensure the effectiveness of the display formats and codes being proposed for operational use. In part, this can be accomplished through the application of existing and new evidence-based human factors design specifications. However, because of the unique changes to the aircrew demands of ATC communications tasks that are associated with DataComm and the new message content introduced by NextGen, such standards must be supplemented by standard assessment methods. These methods are needed to provide comparative performance data as that can be used to optimize text displays as well as less conventional display alternatives, to demonstrate that clearances arriving on the flight deck will be perceived in a timely fashion, and ensure that their interpretation by pilots accurately and unambiguously reflects the intent of the sender.

It should be noted that this requirement to warrant the effectiveness of air-ground communications is not new. The historical evolution of a workable voice radio ATC communications system involved continuous improvement of radio equipment to increase the integrity of the physical signal, as well as the development of a highly refined vocabulary and rigorous message construction procedures that support the inherently limited auditory perceptual and memory capabilities of the human listener and account for the imperfections of the transmission medium. However, as DataComm becomes the primary means of air-ground communication, and the nature and quantity of the required information changes, a new emphasis must be placed on designing communications codes, displays and procedures and on determining the safety and effectiveness of alternative messaging implementations.

Inputs from subject matter experts (SMEs) during this process are an invaluable resource. Nevertheless, as revolutionary changes to the ways in which air traffic operations are instituted in the NAS, these subjective inputs must be supplemented and reinforced by standardized objective assessment methods as efforts are made to efficiently design new display concepts and certify their effectiveness.

### 6.2. Purpose

The purpose of this section is to document a methodological tool for objectively measuring the effectiveness of DataComm messages displayed to aircrew using alternative text phraseology or alternative graphical, symbolic, or multimodal displays. The tool is the product of a research program at Wright State University focused on exploring non-traditional flight deck aircrew interfaces for interaction with DataComm messages. The two-stage approach employed in this research program began with part task simulations to objectively measure the speed and accuracy with which pilots could interpret DataComm messages under various display options. The second stage of the research program involves testing of promising options identified during the initial research in the context of medium-fidelity flight simulation.

The successful application of the part task simulation technique developed in first stage studies was the impetus to document the procedure as a tool that could be used for a variety of DataComm development and certification tasks that are not currently supported by existing technology or Human Factors testing methods.

The following sections of this paper provide a concise description of the message assessment procedure that was used in baseline testing of text messages developed for the SC 214 message set, as well as simple alternative graphic displays. The section concludes with a discussion of how these procedures might be used by organizations participating in the development of ATC phraseology for text displays of DataComm clearance messages, and by flight certification personnel in human factors testing of the effectiveness of DataComm interfaces and display formats proposed for installation in operational aircraft.

### 6.3. Rationale for the Data Communications Message Assessment Tool (DC-MAT)

The DataComm Message Assessment Tool (DC-MAT) described here was developed expressly to provide a standardized test procedure for evaluating the effectiveness of alternative codes for communicating DataComm ATC clearances to pilots using visual flight deck displays. While this methodology was also intended to act as a structured framework for evoking qualitative input from pilots and other SMEs about candidate text, graphical and symbolic displays, its primary purpose was to generate objective data on the relative effectiveness of these displays in communicating ATC clearance information.

In order to yield operationally meaningful measures of the extent to which different display codes produce more or less efficient information throughput, the testing tool was designed as a direct simulation of the pilot's task of responding to a newly received ATC message in the context of a flight scenario. The goal of the part task simulation is to assess pilot performance during the task of "reading" and interpreting an ATC message. Total message interpretation time and accuracy are measured by asking the pilot to decide whether or not to accept the delivered clearance. A clearance is accepted when it is in agreement with the active flight plan and compatible with current phase of flight, or provides a reasonable alternate trajectory to the destination identified in the flight plan. Pilots are instructed to reject a clearance when it calls for a trajectory change that is clearly inappropriate for the current phase of flight (e.g. climb clearance during the descent phase) or that places the aircraft on a path that is not compatible with the destination. Interpretation accuracy is measured by the number of correct accept/reject responses to ATC clearances presented during a test session. Message interpretation time is defined as the elapsed time between onset of the message display to the pilot's binary choice button press response for accepting or rejecting the message.

As described in the succeeding sections, the DC-MAT offers an objective, performance-based criterion for optimizing clearance text and for determining the effectiveness and safety of alternative DataComm clearance display formats. It is implemented on a portable pc-based computer system that makes it practical for use in a variety of system test environments. Most importantly, the DC-MAT provides standardized assessment in a test procedure that has inherent face and content validity by directly measuring the interpretability of a message using the same judgment task that pilots will perform in the operational environment before executing a DataComm clearance or loading it into the Flight Management System.

## 6.4. Description of DC-MAT

### 6.4.1. Equipment and Test Trial Development Software

DC-MAT is implemented on a Windows-based desktop PC with screen oriented in portrait mode, or laptop PC with an accessory LCD/LED screen in portrait mode. Test participant inputs and responses to displayed clearances are entered using a numeric keypad connected to the computer's USB port. The DC-MAT software is written in JAVA. Input to the system for each of a series of scenario-based test trials is a text file that provides the information listed below:

1. Simple text flight plan scenario description including departure, destination, estimated time en route (ETE), estimated time of arrival (ETA), and current altitude;

e.g. "Seattle, Washington – KSEA to Washington D.C. – KIAD

You are at your cruise altitude of FL350.

ETE is 4 hours and 57 minutes.

ETA is 2 hours and 56 minutes."

2. A map display simulating the navigation display found on commercial aircraft and showing the planned route of flight, fixes, waypoints, current aircraft position and altitude.

3. A text clearance (from one element to complex multi-element and concatenated messages).

4. A numbered flight scenario associated with the brief flight plan and map display

5. Any graphical elements/symbols overlaid on the map display for testing alternative message display concepts that supplement or replace the message text.

Text messages for initial development were derived from current RTCA SC-214 / EUROCAE WG-78 Standards for Air Traffic Data Communication Services (RTCA, 2012). The numbered flight scenarios for message testing are constructed by creating flight plans using Goodway flight planning software. For each clearance selected for testing, four scenarios are developed by adding the clearances to a flight plan. Two of these the scenarios introduce clearances that are consistent with the aircraft's flight plan/destination/phase of flight and should receive an "accept" response from the pilot. In the other two scenarios, the clearance is not compatible with the destination/phase of flight and should receive a "reject" response, when correctly interpreted.

The text file designates the information displayed to the test participant about the flight plan and current position of the aircraft, the spatially displayed flight path, and the clearance data. The JAVA program converts these script files into displayed graphics and text.

### 6.4.2. Message Test Procedure

Pilots participating in message display mode effectiveness testing are seated at the computer display with the numeric keypad used to make entries to start a test trial, display the clearance and submit the accept/reject responses. A test session consists of a series of individual trials, each requiring a response to a DataComm message. To begin each trial the participant presses a key that displays the flight plan scenario text in the top "window" with the navigation display map presented directly below the flight plan.

After studying the description, the current map position and route, the participant presses the enter key a second time, causing the ATC DataComm clearance to be displayed. Depending upon the display under evaluation during the trial series, the message may appear in text form in a window to the right of the map and/or as graphical, symbolic or some other format overlaid on the map display. After evaluating the clearance in the context of the flight plan and current situation, the participant responds by pressing the "accept" or "reject" button[1]. The start of the next trial with a new flight plan, scenario and clearance is paced by the participant.

Figure 8 illustrates the screen at the start of a test trial when the flight plan and map are displayed for study. In testing of text displays, the DataComm clearance text area to the right is filled-in with a message for evaluation and response.

[1] It should be noted that the "accept" and "reject" response criteria used in this procedure were selected to provide pilots with an unambiguous judgment standard. Participants are instructed to "reject" when they hold any reservations about the appropriateness of the clearance based on the provided text flight plan and navigation display data, whether or not they might choose to comply in an operational situation after obtaining additional information or following a clarifying voice radio interchange with ATC.

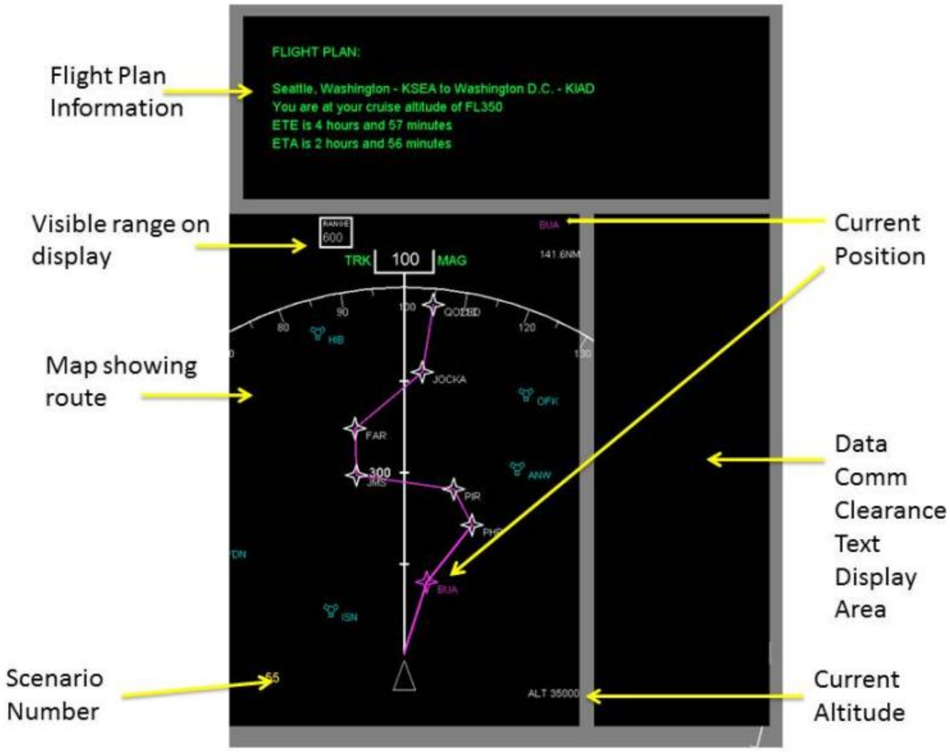



**Figure 8. Screen Shot of Flight Plan and Map Display Indicating Current Situation**

Examples of clearances designed to receive a reject response include those entailing excessive additional distance flown in comparison to the original flight path, an inappropriate altitude for phase of flight, flying to a waypoint already passed, or flying in a direction opposite to, or at greater than 90 degrees off of, the current flight path. Participants are asked to respond as they would during actual flight by accurately evaluating the clearance in a timely fashion and rapidly indicating an intent to comply (accept) or their concern about the acceptability or validity of the clearance by responding in the negative (reject).

The primary measures yielded by each trial are the time needed to produce the accept or reject response after the clearance is presented, and whether the response was correct (accepting a good clearance or rejecting an incompatible clearance) or an error. Ancillary measures of the time used to study the map and flight plan prior to clearance arrival are also available.

### 6.5. Use of the DC-MAT in System Development and Testing

#### 6.5.1. Validating the Effectiveness and Safety of Text Message Phraseology

In 2007, an international group of aviation and air traffic system experts was assembled to undertake a joint RTCA Special Committee 214 and EUROCAE Working Group 78 effort to develop Standards for Air Traffic Data Communication Services in support of NextGen and corresponding European modernization programs. As a part of its ongoing mission, this group has worked to create, assess, and refine a common set of DataComm ATC uplink and flight deck downlink messages to support operations in the full range of environments (e.g. en route, terminal, oceanic) through 2020. The message set includes text forms of existing messages commonly sent using voice radio, as well as modified and new messages designed to support unique NextGen operational concepts and technologies. Selection and phrasing of these messages is done under the auspices of the group and has been guided by inputs from systems specialists, engineers, highly experienced air traffic and pilot personnel, and human factors experts. Candidate text for these messages is examined in an iterative manner by a multidisciplinary team to minimize the likelihood that the documented messages will result in miscommunications and errors.

One application of DC-MAT that we propose is to use it as a means to supplement this approach to message text design and assist in achieving consensus among the experts. Where alternative text message constructions are in competition, or experts are unsure of how accurately a message will convey ATC intent, DC-MAT would provide a way for experts to evaluate the messages in the context of a sample set of common structured operational scenarios. Beyond offering a procedure for formally examining candidate text messages and soliciting expert opinion, DC-MAT would provide objective judgment response time and error data as a basis for choosing message constructions that yield the greatest accuracy and ease of interpretation by a sample pilot group.

The practicality of using the tool in the context of DataComm message design exercises is enhanced by the simplicity of the test procedure and portability across platforms. Ideally, message tests could be conducted remotely by distributed stakeholders and pilots at a time of their choosing by accessing the DC-MAT and pre-defined test trials online. Both the qualitative opinion results and quantitative response time and error data could then summarized and made available during group meetings to aid in the message creation and validation process.

### 6.6. Certifying Alternative Graphical, Symbolic and Hybrid DataComm Displays

The certification process for flight deck aircrew interfaces calls for a different mindset than the research and development process. When engaged in developing new display concepts, the system designer typically uses experimental measurements to explore the design space in an effort to identify an approach that optimizes information transfer, and ease of use while minimizing display reading errors. Somewhat different goals are sought when conducting certification for installation of a new display as a functional component of an aircraft for use in air-ground communications affecting an aircraft's trajectory. In this process, the certification agent uses existing design standards and assessments to determine whether the new display meets minimal performance requirements. These standards typically include specifications for display location, glare reduction, data content, visibility of markings and text, readability and workload. For some of these requirements fixed and easily measurable pass/fail criteria are available to determine whether they have been met by the candidate display. However, in many others like readability or the workload imposed upon the user when interpreting the display, fixed criteria for judging operational suitability are less well-defined.

DC-MAT uses pilot performance measures (speed and accuracy) to assess the interpretability of a message display and would typically fall into this second group of assessments where one can easily assess which of two options is "better", but it is difficult to determine whether either or both meet a minimal acceptable standard. However, because it is proposed for use as a means for certifying alternatives to text-only displays, meaningful performance criteria can be specified for DC-MAT measures as a basis for warranting the safety and effectiveness of graphical and other non-traditional display modes.

Figure 9 and 10 illustrate the basic comparison proposed for certifying the effectiveness and safety of alternative DataComm flight deck displays. Figure 9 shows a DC-MAT display of a complex ATC clearance created by concatenating standardized text message elements derived from the RTCA SC-214 DataComm message set. Figure 10 presents the same clearance displayed using a hybrid graphical option in which the text version is linked to a graphical version overlaid on the active flight plan using numbered diamond symbols.

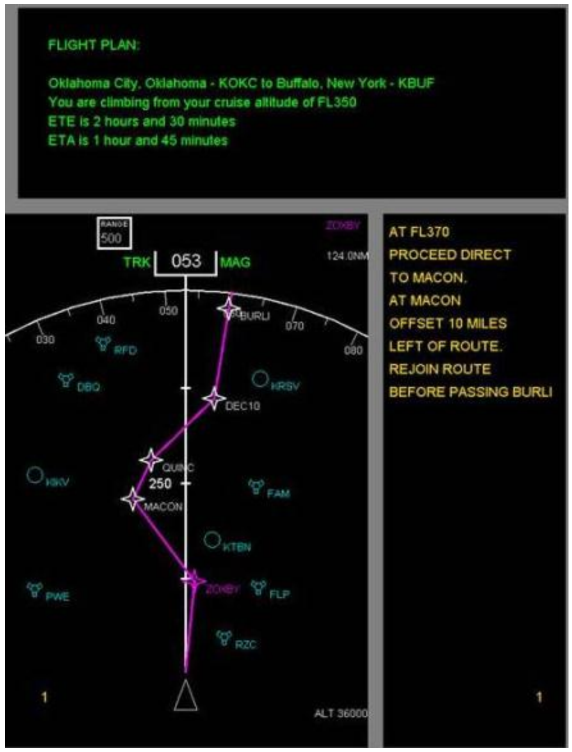



**Figure 9. Criterion for Text-only Message Display**

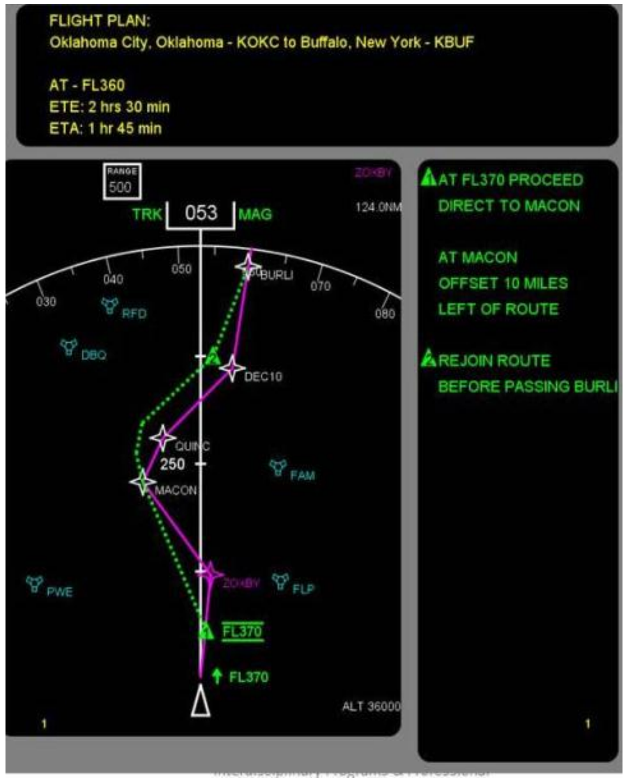



**Figure 10. Sample Candidate Hybrid Graphic Message Display**

Under this rationale, the pass/fail benchmark for certifying the acceptability of alternative displays like that shown in Figure 10 would be whether DC-MAT performance with the alternative meets, or exceeds, that achieved with the traditional text display. That is, the candidate alternative display would be required to yield an error rate in judging the acceptability of a given clearance type that is equal to or lower than that observed under testing with text versions of that clearance type. Likewise, pilot response times for interpreting the alternative display would be required to match, or be faster than, those produced when reading the text-only display.

### 6.7. Future Work for DC-MAT

As discussed in this paper, the DC-MAT has the potential to provide a standardized, portable and highly flexible method for evaluating message text phrasing options or certifying non-traditional message displays. However, additional work will be needed to make the DC-MAT a fully accessible instrument for use by message and display developers or certification personnel. Specific recommended development activities include:

1. Create a simple user interface for insertion of message text options and alternative (graphical/symbolic) message displays into DC-MAT test scenarios.
2. Develop a library of standard flight scenarios (flight plans and current situation descriptions) for use in development of test sessions.

3. Create a database of DC-MAT response times for finalized versions of key SC-214 uplink clearance text messages to provide optional a priori baseline performance criteria for certification of alternative graphical or hybrid displays.
4. Prepare DC-MAT documentation and standard instructions to accompany software or online-accessible tests.

# 7. Appendix 3: Issues with UMs and DMs

Table 1 presents a list of UMs and DMs that resulted in pilot feedback, problems, or high error rates. The error rate selected for cut-off was 80%. This does not indicate an error rate of 80% is acceptable or unacceptable. It was selected because most data were above 80%. The purpose of this information is to provide feedback to the FAA and other entities that show some of the issues that arose during the research related to UMs/DMs.

## 7.1. UMs and DMs do not match which may cause confusion when negotiating via DM requests.

The research indicated that when pilots attempted to create a DM from a list of possible DMs using the TextGen Interface, the text of the DM did not directly match the UM to which the pilot was responding. Table 2 shows the downlink messages made available to the pilots in the experiment, and which DMs to use as a response to the UM messages. The verbiage is slightly different, but the context of the messages still remains consistent.

When pilots used GraphicGen, which allows pilots to edit the UM to create the DM, trying to locate the correct match was no longer an issue. The software automatically created the concatenated downlink message for the pilot after they rejected the clearance. Pilots were only able to change the variables within the downlink messages. They achieved this variable manipulation by physically touching and dragging the graphics on the navigation display.

**Table 1. Pilot and Data Result Feedback for UMs and DMs.**

| UM/DM Number(s) | UM Text | Issue/Feedback & Possible Reason | Simulation Experiment in Which Tested |
|---|---|---|---|
| UM 19 | Maintain [level] (Only used for the Text Condition in Experiment I.) | Correct rejection only 60% of the time under TEXT condition only.<br><br>Pilots continuously stated that since they were not technically cleared to the altitude referenced in UM19 'MAINTAIN [level]', that it will then seem incorrect to accept based on the fact that current altitude may be different from the altitude referenced in the clearance. A change in altitude would constitute a climb or descent, but neither was requested in the clearance. Pilots typically rejected it when the altitude in the clearance was different from their current altitude. | Experiment 1 |
| UM 68 | Rejoin route at or before [position] | Pilots stated that the clearance did not specify when they needed to begin the initialization of the rejoin causing ambiguity. They also stated it was unclear if ATC wanted them to proceed directly to the position referenced, or just before the position. Whenever pilots receive the clearance via voice they expect to rejoin their original filed flight plan at their discretion. It is also understood generally that they rejoin their route immediately. There were many other issues with this clearance once graphics were implemented on the ND. Recommendations related to graphics for this clearance were provided in the recommendation section. | Experiment 1 |
| UM 70 | Expect back on route by [position] | This was confusing when provided by text with no other UM, and when there were no graphics because there is no information about the time. They also were not technically cleared off course. Because this experiment used a static display of a current situation they may not have been situationally aware. This UM may only be relevant following other UMs, even in separate communications. | Experiment 1 |
| UM 78 | At [level] proceed direct to [position] | 50% Correct Rejection for Text condition only. Correct Rejections higher for graphic conditions. | Experiment 1 |
| UM27 | Climb to reach [level] at or before [position] | Low % of Correct Accepts and Correct Rejects across formats. | Experiment 1 |
| UM 79 | Cleared to [position] via [route clearance enhanced] | 70% correct accept under TEXT format. | Experiment 1 |

| UM/DM Number(s) | UM Text | Issue/Feedback & Possible Reason | Simulation Experiment in Which Tested |
|---|---|---|---|
| UM 47 | Cross [position] at or above [level] | 75% correct accept under TEXT format. | Experiment 1 |
| UM 46 | Cross [position] at [level] | Correct reject was 70% for G+T format. | Experiment 1 |
| UM 49 | Cross [position] at and maintain [level] | Correct accept 50% for G+T and 57% for G+T+ASD. | Experiment 1 |
| UM 20; UM190 | Climb to [level]. Fly heading [degrees] | Correct rejections of 40% for G+T and 65% for G+T+updUM. | Experiment 1 |
| UMs listed in next col | Four three element clearances were tested. (20,190,74), (339), (23,94) (65) | All three element clearances resulted in high error rates when used with TEXT format. | Experiment 1 |
| UMs listed in next col | Five four element clearances were tested. (190,20,78), (22,77), (215,20,60), (65,68), (190,20,215) | All four element clearances resulted in high error rates across the various formats. | Experiment 1 |
| UM 77,97,68 | Climb to reach [level] at or before [position]. At [position] fly heading [degrees]. Rejoin route at or before [position] | Correct Accept percent rates varied from 25% (TEXT) to 68% with Graphics. | Experiment 1 |
| UM 23,78,97, 68 | Descend to [level]. At [level] proceed direct to [position]. At position fly heading [degrees]. Rejoin route at or before [position]. | Correct accept rates were 65% for TEXT, 60% for G+T+ASD, and 78% for [G+T+updUM]. | Experiment 1 |

| UM/DM Number(s) | UM Text | Issue/Feedback & Possible Reason | Simulation Experiment in Which Tested |
|---|---|---|---|
| UM 339, 339, 339 | At [position] cleared to [position] via route clearance enhanced (x3) | Correct acceptance of this nine element clearance was at 55% and below for all formats including graphics. Pilots were not accustomed to this type of clearance. | Experiment 1 |
| DM 6 | At [Position] Request [level] | This UM was often confused with "At [level] Proceed Direct to [Position]". Pilots incorrectly selected this message, and they spend sometimes minutes inputting variables into a message that was simply irrelevant in reference to the clearance they are responding to. | Experiment II |
| DM 11 | Request [level]" was made available to pilots in order to respond to two separate UMs that they received which are:<br>1. "CLIMB TO [*level*]"<br>2. "DESCEND TO [level]" | Since "REQUEST [level]" does not specify a climb or descent, then pilots second guessed at times if they were using the most appropriate DM. | Experiment II |

| UM/DM Number(s) | UM Text | Issue/Feedback & Possible Reason | Simulation Experiment in Which Tested |
|---|---|---|---|
| DM 6 | At [position] request [level]" was made available to pilots in order to respond to three separate UMs that they received which are:<br>1. CROSS [position] AT LEVEL [level]<br>2. AFTER PASSING [position] DESCEND TO [level]<br>3. CLIMB TO REACH [level] BEFORE PASSING [position] | Pilots stated that it would have been nice to actually have a CROSSING category for any CROSSING clearance instead of having to look in the Altitude tab where "AT [position] REQUEST [level]" resided. | Experiment II |

**Table 2. UM Clearance and DM Response**

| UM # | Uplink Messages (UMs) | | Downlink Messages (DMs) | DM # | Notes |
|---|---|---|---|---|---|
| 20 / 23 | CLIMB TO [*level*] / DESCEND TO [level] | . . . *translates to* . . . | REQUEST [level] | 6 | Issue |
| 46 / 25 / 27 | CROSS [*position*] AT LEVEL [*level*] / AFTER PASSING [position ATW] DESCEND TO [level] / CLIMB TO REACH [level] BEFORE PASSING [position] | . . . *translates to* . . . | AT [position] REQUEST [level] | 11 | Big Issue |
| 78 | AT LEVEL [*level single*] PROCEED DIRECT TO [*position*] | . . . *translates to* . . . | AT LEVEL [level] PROCEED DIRECT TO [Position] | x | *Fiction* |
| 28 | DESCEND TO REACH [*level*] AT OR BEFORE TIME [*time*] | . . . *translates to* . . . | AT TIME [time] REQUEST [level] | 13 | *No Problem* |
| 76 | AT TIME [*time*] PROCEED DIRECT TO [*position* ] | . . . *translates to* . . . | AT TIME [time] PROCEED DIRECT TO [Position] | x | *Fiction* |
| 64 | OFFSET [*specified distance*] [*direction*] OF ROUTE | . . . *translates to* . . . | REQUEST OFFSET [specified distance] [direction] OF ROUTE | 15 | *No Problem* |
| 65 | AT [*position*] OFFSET [*specified distance*] [*direction*] OF ROUTE | . . . *translates to* . . . | AT [Position] REQUEST OFFSET [specified distance] [direction] OF ROUTE | x | *Fiction* |
| | | . . . *translates to* . . . | REQUEST HEADING [degrees] | 70 | *Never appropriate in experiment* |
| 97 | AT [*position ATW*] FLY HEADING [*degrees*] | . . . *translates to* . . . | AT [Position] FLY HEADING [Degrees]. | x | *Fiction* |

| UM # | Uplink Messages (UMs) | | Downlink Messages (DMs) | DM # | Notes |
|---|---|---|---|---|---|
| | | . . . *translates to* . . . | REQUEST DIRECT TO [position] | 22 | *Never appropriate in experiment* |
| 77 / 339 | AT [*position*] PROCEED DIRECT TO [*position*] / AT [position] CLEARED TO [position] VIA [route clearance enhanced] | . . . *translates to* . . . | AT [position] REQUEST DIRECT TO [position] | 119 | *Used back to back in DM at times* |
| | | . . . *translates to* . . . | DIVERTING TO [position] VIA [route clearance] | 59 | *Not advised to use* |
| 68 | REJOIN ROUTE BEFORE PASSING [*position* ] | . . . *translates to* . . . | REQUEST TO REJOIN ROUTE BEFORE PASSING [Position] | x | *Fiction* |
| | | . . . *translates to* . . . | REQUEST [Speed] | 18 | *Never appropriate in experiment* |
| 188 | AFTER PASSING [*position*] MAINTAIN [*speed*] | . . . *translates to* . . . | AT [Position] REQUEST [Speed] | x | *Fiction* |
| 310 | AT LEVEL [*level single*] MAINTAIN [*speed* ] | . . . *translates to* . . . | AT [LEVEL] REQUEST [Speed] | x | *Fiction* |

### 7.2. Pilot Suggestions Regarding Concatenation of UMs

Pilots indicated they currently never receive a route clearance after “PROCEED DIRECT TO POSITION” (UM74). Pilots accepted placing PROCEED DIRECT at the end of a concatenated clearance.

The concatenated clearances were not well accepted by some pilots because they were comparing them to voice messages. Voice clearances are usually one or two element messages requesting the pilot to change heading, altitude, or frequency. ATC also usually expects the pilot to begin immediate execution of the clearance, reducing ambiguity about when to begin or end the execution of the clearance. For this research UMs were concatenated with some portions of the UM to be executed immediately and others sequentially or at a later time or position.

Most pilots stated that time to review, accept or negotiate a clearance would be a concern. They indicated that clearances must be sent well in advance to execution when multiple elements are presented. They believed that a single pilot aircraft in high traffic or terminal airspace would not be able to aviate and create DMs to ATC.

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

Pilots commented that when ATC provides a heading clearance alone it means to deviate immediately, but momentarily due to traffic. Pilots always expect verbal instructions shortly after they execute the clearance. Pilots commented that if a heading change was used alone under DataComm it would be a deviation from their route. Therefore, they recommended always concatenating the heading message with a reroute message.