2013

Recommendations Supporting Development of Flight Deck DataComm Text and Graphic Display Evaluation Guidance

Jennie J. Gallimore
Wright State University - Main Campus, jennie.gallimore@wright.edu

Ricardo D. Munoz
Wright State University - Main Campus

Stephen B. Kiss
Wright State University - Main Campus

Chang-Geun Oh
Wright State University - Main Campus

Timothy Crory
Wright State University - Main Campus

See next page for additional authors

Authors
Jennie J. Gallimore, Ricardo D. Munoz, Stephen B. Kiss, Chang-Geun Oh, Timothy Crory, Randall Green, Clark Shingledecker ., and Pamela S. Tsang .

Recommendations Supporting Development of Flight Deck DataComm Text and Graphic Display Evaluation Guidance

Jennie J. Gallimore, Ph.D.
Ricardo D. Munoz, Stephen B. Kiss, Chang-Geun Oh, Timothy Crory, Randall Green,
Clark Shingledecker, Ph.D., Pamela S. Tsang, Ph.D.
Wright State University
Dayton, OH 45435

In the Next Generation Air Transportation System (NexGen), voice communications will become less frequent, and most communication will occur via data communications -- uplink messages (UM) (to pilot) and downlink messages (DM) and requests (to ATC). Clearances may include simple one-element clearances such as CLIMB TO [altitude] or complex clearances created by concatenating messages to create flight trajectories that include ATC-authorized route segments, altitudes, and at least one required time of arrival (RTA). Due to the complexity of clearances, aircraft and flight deck equipment manufacturers may seek approval for new and modified flight deck displays to more clearly depict clearances to the flight crew, likely using text and graphics. This research evaluated text and hybrid text and graphic concepts to develop human factors (HF) recommendations for specialists who participate in certification of new and modified flight deck DataComm displays, and as a potential update to AC 20-140, Guidelines for Design Approval of Aircraft Data Link Communication Systems Supporting Air Traffic Services (ATS).

Data communications (DataComm) is one of the 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. 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 challenge for the flight crew will be understanding Trajectory Based Operations (TBO) clearances. Textual clearance displays that provide complex 4D trajectory information may be difficult for pilots to interpret in a timely and efficient manner without error. 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 alone requires pilots to perform a mental transformation that could slow down the understanding of the messages and lead to interpretation errors. This research investigated use of alternative flight deck displays with graphics, hybrid text and graphics, and other formats that could be integrated with existing navigation displays (NDs) or new DataComm displays to 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 purpose of this research was to evaluate text and hybrid graphics and text concepts in order to support the FAA's Aircraft Certification Service need for regulatory guidance to evaluate alternative flight deck displays, and to make recommendations for minimum requirements for system characteristics and display of air traffic clearances on the flight deck.

Background

While studies that examine the effects of presenting information graphically to the pilots in the cockpit on pilot-controller communications are beginning to emerge (e.g., Prinzo, 2003; Wickens et al., 2003), there is a paucity of studies on graphical display of clearance instructions. One early study by Hahn and Hansman (1992) was focused on the relationship of situational awareness to automated Flight Management System (FMS) programming of data linked clearances and the readback of ATC clearances. Situational awareness was tested by issuing nominally unacceptable ATC clearances and measuring whether the error was detected by the subject pilots. The study also varied the mode of clearance delivery: verbal, textual, and graphical. Results showed that graphic depiction of data link routing information received from the controller and embedded in the electronic map display imposed lower workload than either text or spoken representation of the same spatial information. These researchers pointed out that because textual and graphical modes of clearance delivery offered different advantages for processing, a combination of these modes of delivery in a data link presentation might be advantageous.

A research study was conducted that evaluated 39 different ATC clearances from the RTCA SC-214 / EUROCAE WG-78 Standards for Air Traffic Data Communication Services, referred to here as the SC-214 message set under both text and hybrid graphic and text format conditions. The 39 clearances included 1, 2, 3, 4, 5, 6 or 9 element clearances. A single UM with two elements is AT [Position] CLIMB TO [level], where the element is the variable in the clearance that changes. The one nine-element clearance was composed of one UM (UM339) concatenated together three times to give the pilot a new trajectory.

Method

Experimental Design

The experimental design was between-subjects with one independent variable, presentation FORMAT, with five levels. Number of elements is considered a control variable. It was not feasible to create a factorial design with number of elements as a variable because the specific concatenated UMs were different depending on the number of elements. However, this variable allows us to analyze the data at each level of clearance, and to examine performance trends as the number of elements increase.

Graphic Formats

The five formats included the baseline condition of TEXT only, Graphics + Text, Graphic + Text with updated SC214 UMs, Graphics + Text + altitude situation display (ASD) and Graphics +Integrated Text +ASD. Each are brefily described below

TEXT. The text condition included the presentation of a navigation display (ND) with clearances presented in text to the right of the ND. The ND included the current flight path.

Graphics + Text (G+T). This condition included the clearance drawn as a graphic on the ND as well as the clearance presented as text to the right of the ND as illustrated in Figure 1. Both the current flight path (magenta) and clearance are displayed (green).

Graphics + Text + with updated SC214 UMs (G+T+updUM). This is identical to G+T except some UMs had been updated an were therefore updated for this condition.

Graphics + Text + ASD. This condition is the same as G+T conditions except an ASD was designed to provide additional altitude graphics, and was placed below the ND. Figure 2 illusrates the ASD.

Graphics +Integrated Text + ASD. The text was removed from the right of the ND and placed directly on the ND along with the graphics. The ASD was placed below the ND.

Dependent Variables

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

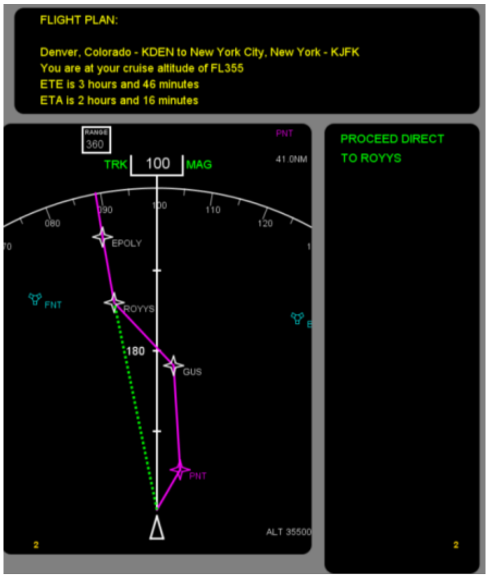
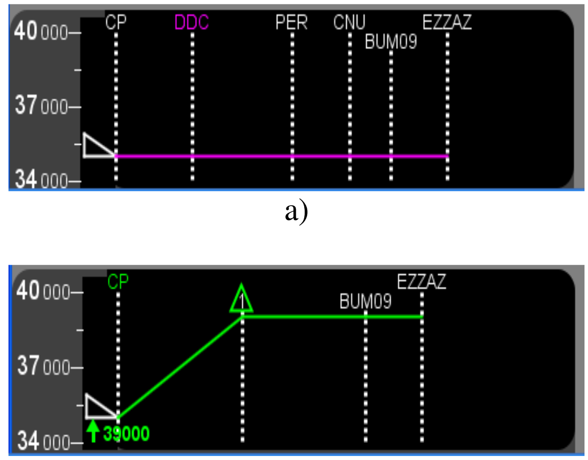


Figure 1. **G+T Format. Green Dotted Line Shows UM Graphic, Proceed Direct to ROYYS.**



a)

b)

Figure 2. **Example of the ASD. Magenta line is current alitude path. Pilot toggles to clearance shown using green line.**

Subjects

Pilots were recruited from the Dayton region and and Cessna Aircraft Company, Wichita, KS. Pilots were screened for a minimum of 100 flight hours. A total of 66 pilots were tested across the various formats. Not all pilots saw all formats. Each pilot participated in two formats maximum. Pilot average age was 43.4 years. The average number of flight hours was 5,926, and 97.5% of the pilots held an instrument rating.

Hardware/Software

The experiment was controlled via a Hewlett Packard (HP) laptop (model Elitebook 8560p) and a portable 18 inch LCD monitor (model L1940T). Connected to the HP laptop was an external 19-key keypad (model FC K19U) data entry device.

The software was custom designed and developed using JAVA programming language and run in the NetBeans IDE. The software controlled the presentation of all display formats, timing, and data collection.

Procedure

The pilot sat in front of the screen with a small keyboard input device. The pilot pressed the 'Enter' key when ready to evaluate the current flight situation, and a timer was started. The pilot reviewed the flight plan and map until they understood the current situation. Once they became familiar with the situation, they pressed the Enter button again and the flight situation study time was recorded. Next, the clearance was displayed, the flight plan text was removed, and the response timer was started again. Pilots had the option of displaying the flight plan again by pressing the backspace (BS) button. After reviewing the clearance, the pilot either accepted or rejected the clearance by pressing 1 or 3 respectively on the external keypad. The judgment was based on the information provided to the pilot through the flight plan, navigation display, UM text and when relevant the ASD.

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

Results and Discussion

An ANOVA was conducted using the procedure PROC MIXED to deal with unequal N across conditions. The analysis was conducted with two IV variables: FORMAT (text and graphic conditions) and RESPONSE (Correct Accept or Correct Reject). The use of RESPONSE as an IV in the analysis provided the ability to analyze whether the pilots correctly accepted or rejected clearances based on FORMAT type.

The exploratory experiment was designed to evaluate performance differences between text and graphic conditions by comparing the baseline TEXT condition to the G+T condition. Figure 3 illustrates the trend of increased response time as the number of elements increase for both TEXT and G+T. The increase in MRT for TEXT, that is the slope, is much greater as the number of elements increase compared to that of G+T. The decrease of MRT for the nine element clearance for G+T is most likely due to the fact that pilots tended to reject these clearances more than accept them. (Correct rejections were 94.17% while correct accepts were 45.83%). Correctly rejecting a clearance was always faster than correctly accepting a clearance. The results indicate that a hybrid of graphics and text is not needed for one and two element clearances. However, for three elements and above graphics and text improved MRT.

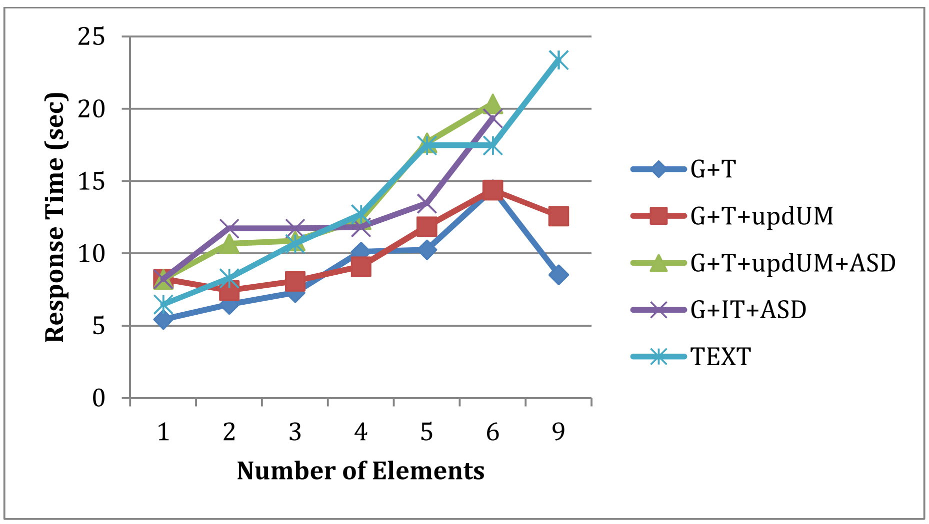


***Figure 3*. Mean response time as a function of format and number of elements in a clearance.**

There are some performance differences among the graphic formats. Specifically when the ASD was included MRT increased. Pilots did not think the ASD was necessary as altitude was available on the ND. Figure 3 illustrates that the two conditions with ASD are grouped together across number of elements, while the G+T hybrid conditions (G+T+ updUM) are grouped with lower MRTs. TEXT and G+T+ASD results are very similar.

Figure 4 illustrates the mean percent correct across the graphic conditions and number of elements. Although the four element condition showed no significant differences, the p value was only .01 below the 0.05 criterion. In this case the trend is for G+IT+ASD to be significantly different than G+T. The five element clearance also showed a significant difference for G+IT+ASD compared to G+T and G+T+ASD. For six element and nine element clearances there was no difference across graphic formats. There is a need for additional research to ensure the difference in mean percent correct across graphic formats. There was a strong trend suggesting the need for additional research related integrating text (G+IT+ASD) onto the ND rather than separating text and eliminating the ASD.

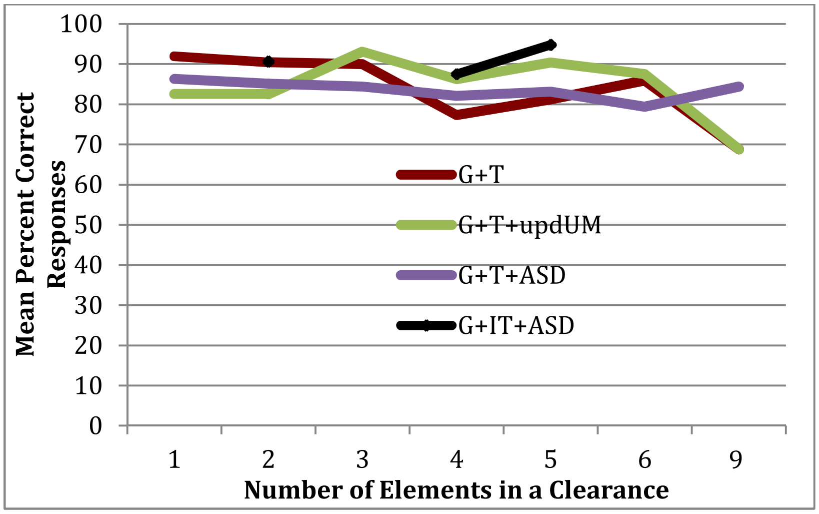


Figure 4. **Mean Percent Correct Responses to Accept a Clearance as a Function of Format.**

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

Recommendation Examples

The primary result of this exploratory research was the development human factors recommendations. Examples of recommendations are presented in Table 1. Readers are referred to the report for more in-depth descriptions, rationale, and graphic examples.

Table 1
Example recommendations based on human-in-the-loop research.

Category	**Recommendation**
Coordinating Text with Graphics	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.
Distinguish between simultaneous versus sequential UMs and DMS.	The graphic and text should clearly indicate simultaneous versus sequential operations.
Rejoin Route Graphics	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. However, this would allow the pilot to rejoin as soon as 30 seconds and still be in compliance. If the intention 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.
Current Setting of Range Level for DataComm Graphic Displays	When a new clearance appears the range of the ND may not be at the correct setting to view the graphic appropriately. Changing the range automatically may confuse the user. The range of the DataComm display should remain at the last setting the user applied.
UM visibility after pilot decision.	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.

Conclusions

This research evaluated text and hybrid text and graphic concepts to develop human factors (HF) recommendations for specialists who participate in certification of new and modified flight deck DataComm displays, and as a potential update to AC 20-140, Guidelines for Design Approval of Aircraft Data Link Communication Systems Supporting Air Traffic Services (ATS).

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

Acknowledgements

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.

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.

References

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.

Gallimore, J.J., Shingledecker, C., Tsang, P.S., Oh, C., and Kiss, Stephen B., (2011). Interim Literature Review Report for Flight Deck Display and Control Requirements Human Factors Study. Technical Report prepared for FAA, NextGen Advanced Concepts and Technology Development, Human Factors Division (ANG-C1), DTFAWA-10-A-80021., Wright State University, Dayton, OH 45305

Gallimore, J.J. Kiss, S.B., Munoz, R.D., Oh, C., Crory, T., Ward, B., Green, R., Shingledecker, C., and Tsang, P. (2013). DataComm – Display Alternatives for the Flight Deck: Overview and Human Factors Recommendations. Final Tech Report Vol 1 & 2. FAA NextGen Advanced Concepts and Technology Development, Human Factors Division (ANG-C1), DTFAWA-10-A-80021. Wright State University, Dayton OH, 45435. *Available at www.hf.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

Prinzo, O. V. (2003). Pilot's Visual Acquisition of Traffic: Operational Communication from an In-Flight Evaluation of a Cockpit Display of Traffic Information. *The International Journal of Aviation Psychology*, 13(3), 211-231.

Wickens, C. D., Goh, J., Helleberg, J., Horrey, W. J., & Talleur, D. A. (2003). Attentional Models of Multitask Pilot Performance Using Advanced Display Technology. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 45*(3), 360-380.