

*ADVANCED GRAPHICAL USER INTERFACE  
FOR NEXT GENERATION FLIGHT  
MANAGEMENT SYSTEMS*

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## **ABSTRACT**

Alternative Flight Management System (FMS) human interface concepts need to be investigated as the complexities of understanding and operating this equipment continue to burden and confuse an already inundated pilot. Improvements, modifications, and alternative human interface strategies have been pursued to eliminate and/or significantly reduce these problems. However, human interface problems continue to exist.

Recent modifications to an Advanced Graphical FMS were evaluated in a robust pilot-in-the-loop simulator by researchers at Rockwell Collins Advanced Technology Center in 1999. These improvements, which include alternative display formats and interface techniques for conducting flight plan editing tasks revealed statistically significant results favoring the Advanced Graphical FMS human interface compared to a conventional CDU-type FMS. This paper will detail these results and provide recommendations.

## **KEYWORDS**

Flight Management System (FMS), Cognitive Function Analysis (CFA), workload, reaction time, error rates, graphical user interface (GUI), control display unit (CDU), pilot-in-the-loop simulator.

## **BACKGROUND AND PROBLEM**

The FMS is an integral part of today's modern aircraft. Increased aircraft performance and the reduction of pilot workload are touted as the benefits for the addition of this type of automated equipment to the flight deck. However, recent accidents and incidents involving glass-cockpit aircraft have suggested that the current generation of cockpit automation may have created new operational burdens and new kinds of failure modes in the overall human-machine system [1,14]. Today's FMS is not immune, it has been scrutinized by leading aviation researchers, pilots, and safety officials for its opaque interface and difficulty of use during nonstandard flight operations. There are mode confusion errors, lack of support to deal with increased cognitive demands, and certain FMS operations are complex and involve a large number of physical and cognitive operations [11,12].

Improvements and alternative human interface strategies have been pursued to eliminate and/or significantly reduce these problems. Industry, government agencies, and academia have explored innovative methods to reduce and or eliminate some of the human interface problems encountered with the FMS. Researchers have addressed means to increase the usability of the FMS by focusing on the underlying functionality of the system and how it matches the user's expectations [3, 4, 5, 6, 7, 9, 10, 13]. However, human interface problems continue to exist.

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Previous efforts by Rockwell Collins Advanced Technology Center (ATC) Human Interface Technology Group to significantly improve the human interface to the FMS have been successful [3, 4, 5, 6, 7]. An Advanced FMS prototype was developed which utilized a graphical user interface (GUI). Previous part-task simulation studies of this GUI FMS prototype conducted in 1998 and 1999 produced findings supporting ATC researcher's hypotheses that an alternative GUI display format could significantly eliminate and/or reduce human interface problems between pilots and the FMS. These early evaluations were important to identify which GUI concepts worked well and which did not. ANOVA results from these evaluations revealed statistically significant findings at the 95<sup>th</sup> level of confidence. The Advanced GUI FMS Human Interface display formats produced quicker reaction times, fewer operator errors, lower levels of mental workload, and higher subjective ratings (Usability, Learnability, and Overall Attitude) than a CDU type FMS [4, 5, 6, 7]. However, due the limited nature of these preliminary studies more research was needed to explore additional FMS functions beyond the initial investigations in order validate these results. Therefore, in 1999 ATC researchers integrated the Advanced GUI FMS with a FMS simulation tool and an aircraft simulator in order to evaluate these GUI techniques in a robust pilot-in-the-loop simulation.

This paper will discuss the results of this integrated GUI FMS and provide recommendations for future research efforts.

### **OBJECTIVE**

The overall objective for this project in 1999 was to design an advanced FMS display/interface that will significantly reduce and/or eliminate human interface problems between users and the FMS. Specific sub-objectives are: research, integrate, and evaluate alternative human interfaces that will address additional FMS functionality, increase the Advanced GUI FMS prototype's simulation capability by integrating it with an existing "FMS Simulation Tool", and extend these interface techniques to the management of the entire display system.

### **APPROACH**

Constantly searching to improve the human interface of next generation aircraft displays the following activities were pursued in 1999:

- Add additional FMS functionality to the Advanced GUI FMS prototype.
- Research and investigate appropriate human interfaces to enhance the graphical user interface to the Advanced GUI FMS prototype.

- Integrate the Advanced GUI FMS prototype with an existing FMS simulation tool for a more realistic evaluation of its alternative display concepts

## PROGRESS

Modifications and improvements to the Advanced GUI FMS prototype were implemented after carefully examining results from previous part-task human factors evaluations of the GUI FMS prototype. The most common functions a pilot performs with an FMS were identified, rapidly prototype using Virtual Applications Prototyping Software (VAPS™) from Virtual Prototypes Inc. of Montreal, Canada, and integrated into the Advanced GUI FMS prototype.

Specific FMS operations that are performed currently with the CDU-type interface, such as building and editing a flight plan, were carefully analyzed to see how these specific operations might be improved by utilizing an alternative human interface. Numerous structured interviews with professional pilots were conducted throughout the year and feedback from these pilots coupled with human factors analyses enabled researchers to modify the GUI FMS prototype. The following set of pictures (Figures 1 - 4 ) show some of these alternative GUI FMS human interface concepts.

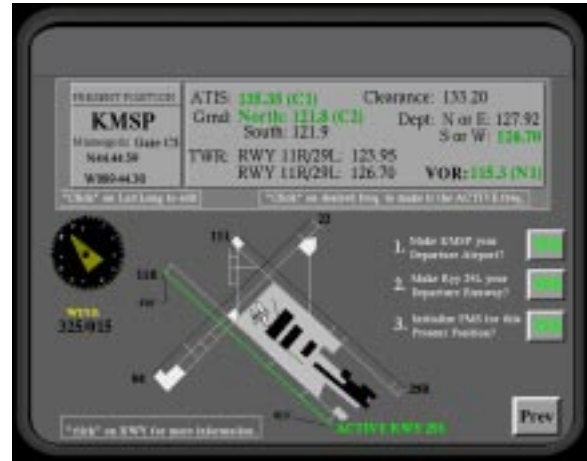


Figure 1. Example of the Position Initialization Page



Figure 2. Example of entering destination airport



Figure 3. Giving assistance and feedback to user.



Figure 4. Example of selecting icons to rapidly manipulate the GUI FMS display format

In order to evaluate the Advanced FMS prototype in a more realistic/robust environment the Advanced GUI FMS prototype was integrated with an FMS simulation tool. Furthermore, the prototype was integrated with Rockwell Collins Advanced Display Concept (ADC) lab's aircraft simulator (Integrated Cockpit Simulator - InCS), enabling ATC researchers to evaluate the effects of these alternative GUI FMS display formats in a true "pilot-in-the-loop" simulation (see Figure 5).

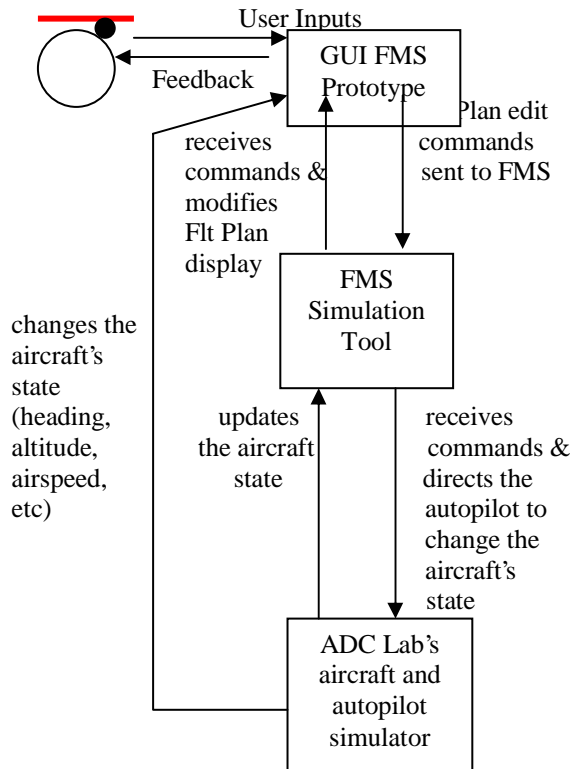


Figure 5 - Advanced FMS integrated with FMS simulation tool and aircraft simulator

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Alternative human interface techniques for creating a flight plan and then editing that flight plan were evaluated in this pilot-in-the-loop simulator. Basic and complex tasks were evaluated. An example of a basic task is proceeding direct to NAVAID on or off your flight plan. A more complex task would require the pilot to perform a hold operation and then edit some specific parameters associated with the hold.

## **METHOD**

Participants. Four subjects participated. All were professional pilots with a mean flying time of 10,400 hours and 27.75 years mean flying experience.

Data Recording: Data was recorded by the experimenter with an analog stopwatch using observational methods. Reaction time was recorded as well as the number of errors made by the subjects while performing the required task.

Display Formats. Two different display formats were evaluated. The first format was the Advanced FMS Interface utilizing a graphical user interface format. The second was a conventional CDU-type FMS display format.

Scenario. The test scenario presented and thoroughly explained to the subjects was a simulated flight from Minneapolis-St. Paul International Airport to Chicago

O'Hare International Airport and between Cedar Rapids Airport and to Chicago O'Hare International Airport. Pilots would build and then fly in a robust pilot-in-the-loop simulator a representative flight between these two cities.

Experimental Design. The experiment was organized as a 8x2x4 repeated measures design.

Independent Variable. Display formats and subjects were used as factors. The Advanced Graphical FMS Human Interface display format served as the experimental condition while a conventional CDU-type FMS text based display format with line select keys and keypad served as the baseline. The final factor was the subjects themselves.

Dependent Variables. Three dependent measures were taken: 1) reaction time to complete a given task, 2) number of errors made by subjects while performing the task, and 3) subjective data. Subjective data was ascertained by using the Cognitive Function Analysis (CFA) method to analyze the pilot-interface interaction for these tasks [ 2] and a modified Subjective Workload Assessment Technique (SWAT) [ 8].

## **PROCEDURE**

Subjects were randomly assigned to one of the two FMS display formats. Subjects would first complete the FMS

tasks on either the Advanced GUI FMS prototype or the

frequency, only display formats and flight plans varied.

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CDU-type FMS. A very short break would follow the first test condition, then subjects would complete the same FMS tasks using either the Advanced GUI FMS or CDU-type FMS. A prerecorded audio tape simulating Air Traffic Control messages was played during the test to ensure consistency of information presented across all subjects.

Subjects were required to initially create a flight plan from Minneapolis to Chicago O'Hare, including the integration of a standard instrument arrival (STAR). Subjects completed this task a minimum of three times. The simulated flight would begin when subjects completed the training session for creating the flight plan task and all other FMS tasks that subjects would complete during the simulated flight, such as proceed direct to a NAVAID or waypoint, Hold, complete a bearing/distance task off a NAVAID, change your landing runway on short final, etc.. Before the simulated flight began all subjects were given a minimum of five practice trials for all FMS tasks to be completed during the flight or until subjects stated they felt comfortable with the specific FMS task.

To reduce practice effects that might occur when flying the simulated route between Minneapolis and Chicago subjects created and flew a completely different flight plan with the CDU-type FMS. Pilots created a flight between Cedar Rapids, Iowa and Chicago O'Hare. All the FMS tasks for the two test conditions were identical in type and

Due to time constraints pilots began the flight from Minneapolis to Chicago half way between these two cities at FL250 and 400 IAS.

Data recording began after the Air Traffic Control gave a command to the subject to perform a given task, such as "BizJet 25 proceed direct to Dells for traffic" and ceased when the subject stated he had completed the task and was cognizant of the results for that specific task.

## RESULTS

Results revealed statistically significant findings favoring the Advanced Graphical FMS Human Interface prototype when compared to a conventional CDU-type FMS for these common FMS tasks. These findings replicate previous studies conducted in 1998 and 1997 increasing the reliability and credibility that the alternative GUI FMS display formats developed will significantly reduce and/or eliminate human interface problems between users and the FMS.

The ANOVA revealed a statistically significant main effect for display format. Reaction time, error rates, and subjective pilot ratings all showed statistically significant differences between the GUI FMS and the conventional CDU type FMS. The following paragraphs will highlight

some of the specific FMS tasks that were found to be statistically significant.

The specific FMS tasks that are statistically significant for reaction time are:

Creating flight plan [F (1,22)=29.09; p<.0000]

Bearing/distance task [F (1,22)=4.81; p<.0390]

Hold task [F (1,22)=11.90; p<.0022]

Exiting the Hold task [F (1,14)=19.80; p<.0005]

Runway Change task [F (1,14)=22.43; p<.0003]

The other completed FMS tasks closely approached the p<.05 level of significance but did not meet this criteria.

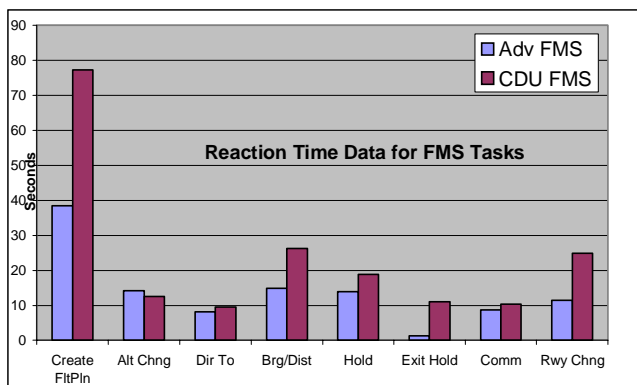


Figure 6. Reaction time data for FMS tasks evaluated

Figures 7 - 9 depict some of the GUI FMS human interface concepts evaluated.



Figure 7. Example of Direct To Dells VORTAC



Figure 8. Example of entering an altitude restriction for the  
Dells VORTAC



Figure 9. Example of the Comm/Radio page

The following are the specific FMS tasks that are statistically significant for error rate:

1. Creating a flight plan [F (1,22)=4.56; p<.0439]
2. Direct To task [F (1,38)=7.10; p<.0112]
3. Hold task [F (1,22)=7.85; p<.0103]
4. Runway change task [F (1,14)=5.64; p<.0323]

The other FMS tasks completed closely approached the p<.05 level of significance but did not meet this criteria.

Furthermore, ANOVA results revealed statistically significant findings between these alternative display concepts and the conventional CDU type FMS when analyzing the expert pilot's subjective ratings with the CFA and modified Subjective Workload Assessment Technique (SWAT) [F (1,12)=42.05; p<.0000].

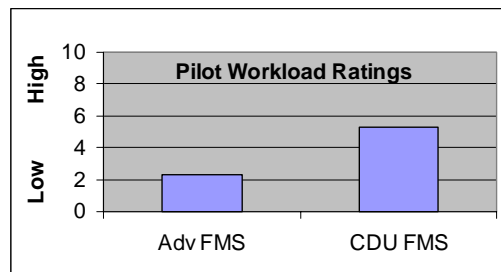


Figure 9. Pilot Workload Ratings

Some of the ANOVA findings for the CFA are:

1. Data affordance [F (1,14)=53.71; p<.0000]
2. Long term memory [F (1,13)=7.15; p<.0190]
3. Display formats [F (1,14)=8.24; p<.0123]
4. Error tolerance [F (1,13)=13.47; p<.0028]
5. Keystroke number [F (1,14)=9.73; p<.0075]
6. Ease of Use [F (1,14)=29.76; p<.0000]
7. Learnability [F (1,14)=20.23; p<.0005]

8. Overall attitude [F (1,14)=18.17; p<.0007]

techniques, compared to a conventional CDU-type FMS.

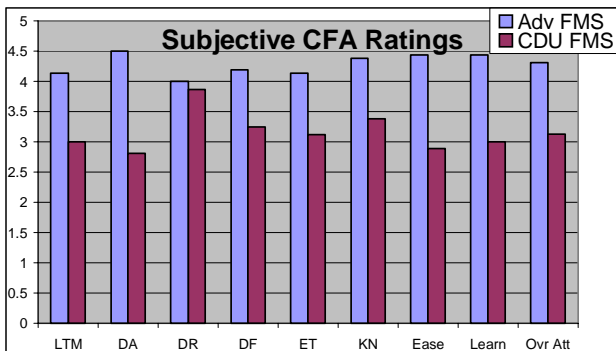


Figure 10. Cognitive Function Analysis Ratings

Comments from the expert pilots who participated in this study were very encouraging. Pilots stated the GUI FMS interface technique was “very intuitive”, “very easy to understand how to use”, and the display format tested is “going in the right direction for improving the interface between pilot’s and the FMS”.

## CONCLUSIONS

Over the past two years our analyses have supported the position that a GUI FMS interface will significantly reduce and/or eliminate human interface problems between pilots and this complex piece of equipment. We have demonstrated some alternative solutions and obtained statistical support for these alternative human interface

We have evaluated these concepts in a robust pilot-in-the-loop simulator and have shown it is entirely feasible to completely integrate an FMS simulation tool, aircraft simulator, and alternative FMS human interface without modifying the underlying software code to the FMS simulation tool. The direct results of these efforts have yielded statistically significant objective and subjective findings revealing the Advanced Graphical FMS Human Interface prototype significantly improves the interface between pilots and this complicated equipment.

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