DOT/FAA/AM-99/26

Office of Aviation Medicine
Washington, D.C. 20591

GPS User-Interface Design Problems: II

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November 1999

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-99/26	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle GPS User-Interface Design Problems		5. Report Date November, 1999
		6. Performing Organization Code
7. Author(s) Williams, K.W.		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency name and Address FAA Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, SW. Washington, DC 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplemental Notes		

16. Abstract

This paper is the second of two of a review of human factors problems associated with the user-interface design of a set of Global Positioning System (GPS) receivers, certified for use in aircraft for instrument non-precision approaches. Both papers focus on design problems associated with the interfaces and specific inconsistencies across the set of interfaces that could cause confusion or errors during operation. Some specific problems addressed involve the placement of units in the cockpit; the use and design of moving-map displays; and problems associated with changes in course direction indicator sensitivity. Recommendations for solving some of the problems are provided, as well as suggestions to the FAA, GPS manufacturers, and pilots regarding the future development and use of these products.

17. Key Words Global Positioning System, Human-Computer Interface, Aircraft Displays, Applied Psychology		18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 11	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

This research is part of the Civil Aeromedical Institute general aviation human factors research program. Program direction is provided by the Aircraft Certification (Small Aircraft Directorate, ACE-100) and General Aviation and Commercial Division (AFS-800) sponsors.

The author expresses his appreciation to Steve Jackson and Steve Winter of the FAA's Technical Programs Division, Flight Procedure Standards Branch (AFS-420) for their invaluable assistance in providing information about the many GPS products currently on the market.

GPS User-Interface Design Problems: II

ABSTRACT

Several Global Positioning System (GPS) receivers were reviewed and human factors problems associated with the user interface were noted. The problems documented below include specific control and display problems, design inconsistencies across units, and general design problems that apply to all of the units reviewed. Discussing these problems highlights the need to make pilots aware of issues that may require specific training or other preventive measures. Recommendations for design improvements are provided.

INTRODUCTION

This paper is the second in a series of papers that review human factors problems associated with the user-interface design of a set of Global Positioning System (GPS) receivers, certified for use in aircraft for instrument non-precision approaches. No GPS products are mentioned by name, since the aim of the paper is not to criticize a particular GPS manufacturer. Instead, the paper focuses on design problems and how these problems affect the pilot.

Data Collection

Most of the human factors problems reported in this paper were obtained from interviews with subject matter experts from the Federal Aviation Administration's (FAA's) Technical Programs Division, Flight Procedure Standards Branch (AFS-420). Additionally, data were collected from an FAA technical report (Winter & Jackson, 1996), as well as through FAA internal memoranda (i.e., personal communications, S. Jackson, August, 1997; S. Jackson, February 18, 1998; S. Jackson, May 22, 1998, S. Winter, September 25, 1996). Some information was gathered from the Aeronautical Information Manual (FAA, 1998). Finally, data were taken from observation logs of a recently conducted operational test of a GPS Wide Area Augmentation System (WAAS), and from personal observation from the WAAS test.

Problems Previously Covered

In the first paper of this series (Williams, 1999a), several human factors problems related to GPS receiver design and use were reported. These problems included the overall complexity of operating a GPS receiver, lack of adequate feedback for some button activations, the lack of an "undo" function, and the poor placement of buttons on the interface of some receivers. Knob issues discussed included a lack of feedback regarding the position of knobs and the inability of some receivers to "wrap around" from A back to Z when inputting alphanumeric information. Labeling problems that were discussed included variations in the annunciator panels from unit to unit, particularly in regard to the function for suspending automatic sequencing of waypoints in the approach route. A second problem noted with the annunciator panels was a lack of co-locating the panel with the GPS unit or with the navigational instrument used during an instrument approach.

Button labeling was also discussed. There is a general lack of uniformity across units in regard to the number, position, and labeling of buttons. In addition, most units have one or two ganged knobs. Function activation accomplished through knob turns in one unit might be accomplished by button activations in a second unit.

Procedural problems with the units were also covered, including workload associated with the selection of an alternate airport, issues associated with automatic vs. manual waypoint sequencing, and the inconsistent functionality of the equipment being driven by the GPS unit, such as the horizontal situation indicator and instrument landing system display. The functionality of these devices is highly dependent upon the manner in which they are installed in the aircraft and can be different from aircraft to aircraft, even though the GPS unit is the same. For details of these problems and suggestions for dealing with them, see Williams (1999a).

Design Problems

As in the original paper (Williams, 1999a), the following design problems are not intended to be an exhaustive list. In fact, many problems were not included because of time and space constraints or because they had been discussed in the previous paper. Nor are the problems presented in any particular order of importance since the importance of a specific problem cannot usually be determined without looking at how often it occurs and its effect on pilot workload and performance. Further research is required to make these determinations.

Unit Positioning

Because the GPS unit is an add-on device in most cockpits, the location of the unit is limited by the instrumentation already in place. In many instances, this leads to the suboptimal placement of the unit. Frequently, the unit is placed farther away from the pilot than it should be, leading to difficulty in reading the display and in manipulating the controls. Consequently, before approving a particular installation, the pilot should determine beforehand if the unit will be too far away for proper use.

A second problem with unit positioning occurs when the GPS unit is placed in the center console between the pilot and co-pilot seats. *The Instrument Flying Handbook* (FAA, 1980), in a discussion of spatial disorientation, gives a method for purposely inducing spatial disorientation in a student pilot for training purposes. It states, "The instructor starts a positive, coordinated roll toward a 30° or 40° angle of bank. As this is in progress, the student (initially with eyes closed) should tilt the head forward, look to the right or left, then immediately return the head to an upright position. The instructor should so time the maneuver that the roll is stopped just as the student returns the head upright. *An intense disorientation is usually produced by this maneuver...*" (p. 11, italics added). The manual continues with actions to prevent spatial disorientation including the following, "Avoid sudden head movements, particularly during takeoffs, turns, and approaches to landing" (p. 11). By locating the GPS unit in the center console, the pilot is forced to move his or her head down then back up. This movement will likely occur during approaches and could also occur during turns. Positioning a GPS unit in this location would result in a direct conflict with the instructions for avoiding spatial disorientation.

Display Problems

Multiple Pieces of Information. Often, several different pieces of information are co-located on the GPS display. Because these displays are relatively small, the information cannot be widely separated. This can lead to confusion while reading the display. Winter and Jackson (1996) reported the results of flight-testing two separate GPS displays at the FAA Technical Center in Atlantic City, NJ, and at the University of Oklahoma in Norman, OK. They noted that "A common mistake on the ... receiver was for the subject pilots to dial in the ground speed value, instead of the desired track, into the CDI course window" (p. 4).

Moving-Map Displays. The presence of a moving-map display can greatly increase a pilot's situational awareness and has been shown to greatly improve pilot decision-aiding (Aretz, 1991; Hofer & Wickens, 1997; Williams, 1999b). However, there have been some human factors-related problems noted with moving map displays. One problem relates to the small screen size of most units. Because these units must be installed in the panel to be certified for instrument approach use, manufacturers have been constrained by how much room they have available. While newer receivers are larger, many of the older text displays have room for only 1 or 2 lines of text. Trying to place a moving-map display on these units can lead to a very small and crowded display. Figure 1 shows an example of a moving-map display from one of the larger display units on the market.

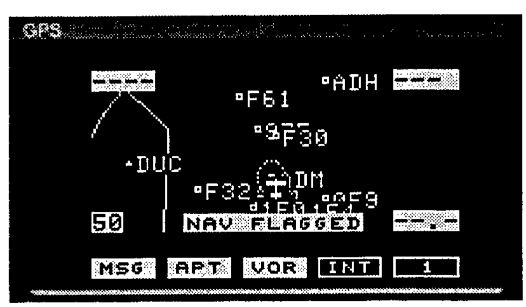

Figure 1: Example of a moving-map display

Looking at the figure, note the amount of overlap of symbols. Of course, the display has options for adjusting the amount and type of symbols that are displayed, whether identifiers are included in the display, and the scale of the map. However, if a pilot has a need for displaying these options (such as airport identifiers), then a certain amount of clutter is inevitable simply because of the small screen size.

Not surprising then, when two airports are in close proximity, and they have similar identifiers (e.g., F28 and F29 identify two Oklahoma airports less than 10 miles apart), pilots can become confused as to which airport they are viewing on the map display. This is especially likely when the map is being used in an other-than-north-up mode, where the orientation of the two airports can change depending on the direction of travel of the airplane. In most of the units reviewed that had a moving map, there was no immediate indication on the display of the selected map mode (i.e., track-up, north-up, etc.). Verification of the map mode required leaving the map display and going to a page where the display characteristics are selected. If the pilot is using the map for strategic planning (e.g., deciding on an airport at which to land in the presence of severe weather), it is vital that the pilot realize the orientation of the map that is being used.

One final problem that has been noted with moving-map displays is the tendency for some pilots to try to use the map for real-time course guidance (Steve Jackson, personal communication, January, 1999). Given a course line that is essentially 1 mile wide, and a plane symbol that is 5 miles wide, the use of the display for real-time course guidance is problematic, since the display does not provide enough resolution to ensure accurate course following. During the approach, the problem is even more critical. Furthermore, anything that tends to focus the attention of the pilot inside the cockpit is problematic, as previous studies have shown (Williams, 1998; Wreggit & Marsh, 1998). One possible way to address this issue would be to ask GPS manufacturers to include a warning in their documentation regarding the inaccuracies of the moving map display.

CDI Sensitivity. One final display problem to be discussed concerns the sensitivity of the course direction indicator (CDI). During an approach, the CDI gives an indication of the plane's horizontal position relative to the intended approach course. The CDI can be either depicted directly on the GPS display, or the unit can be controlling a separate CDI such as is present in an instrument landing system (ILS) display. For current ILS systems, the signal diverges continuously from the point of origin, as is depicted in Figure 2. For these systems, the sensitivity of the CDI increases continuously as the airplane approaches the signal source.

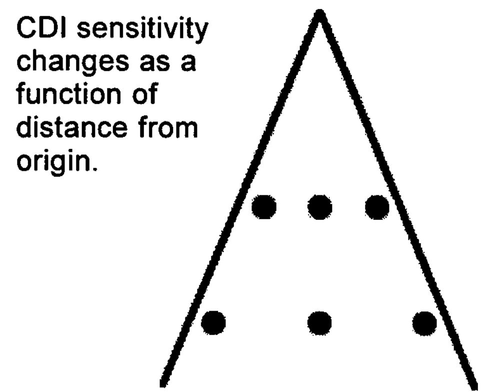

Figure 2: CDI sensitivity for current ILS systems

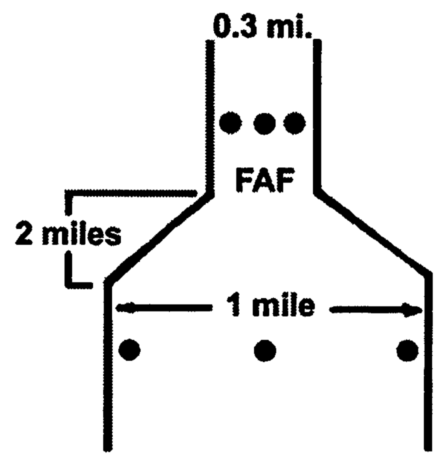

Figure 3: CDI sensitivity for GPS systems

For the panel mounted GPS unit, CDI sensitivity is controlled programatically by the unit itself. In the en route mode, the CDI sensitivity is set at 5 miles. Beginning at 30 miles from the final approach fix (FAF), the CDI sensitivity is reduced to 1 mile. When the airplane is 2 miles from the FAF, CDI sensitivity is ramped down from 1 mile until it reaches 0.3 miles at the FAF. This situation is depicted in Figure 3.

Consider the situation in which the airplane is slightly offset (e.g., 0.1 mile to the right), but parallel to the programmed course. For non-GPS-driven displays, the CDI would drift slowly to the right, from the point at which the navigation signal was first received. Small corrections by the pilot would maintain the airplane's course closer and closer to the programmed course. On the other hand, for a GPS-driven display, the CDI would remain slightly offset, but unmoving, beginning at 30 miles from the FAF. It would remain still until, at 2 miles from the FAF, the indicator would begin to move out as the sensitivity was ramped down from 1 mile to 0.3 miles.

Observation of pilots who have encountered this situation has shown that, if they do not realize that a change in CDI sensitivity is occurring, they conclude that their heading has changed and that they have started to drift off course (Steve Jackson, personal communication, January 1999). Corrections for this "course drift" have sometimes been quite drastic. There is a light on the annunciator panel and usually a change in the receiver display that indicates the approach is active. When this light turns on, it indicates that the unit has begun to ramp down the CDI sensitivity from 1 mile to 0.3 miles. However, pilots are not told explicitly that the sensitivity is changing in all receivers. They must simply know that this occurs at a certain point in time as indicated by the annunciator light. An explicit indication of CDI sensitivity would be better and would lead to less pilot confusion.

Miscellaneous Problems

Button Label/Function Mismatch. Functions are sometimes assigned to buttons in such a way that the label on the button has no relevance to the function it performs. This occurs because of the large number of functions that are performed with the unit, compared with the relatively small number of controls (buttons, knobs, etc.) for performing those functions. One example of this is a unit that uses the direct-to button for selection and de-selection of the autosequencing mode (S. Winter, personal communication, September 25, 1996). One solution to this mismatch is to have programmable button labels, similar to those seen on multifunction displays found in military aircraft. These buttons are co-located next to the display, with the button function presented above or to the side of the button on the display. The same button can then be used for several functions, while the function name changes on the display.

A similar problem occurs when two buttons on the unit have intuitively equivalent labels. For example, at least one of the units on the market has a button labeled "select" and another labeled "enter." For many units, as well as for other computer applications, the "enter" button is used to make a selection. Users can easily be confused about whether a particular action requires the "select" button or the "enter" button. The user must memorize, for a particular function such as selecting an approach, which of the buttons is required for that selection.

Air Traffic Control Experience. Because GPS approaches are not yet widely used, air traffic controllers do not have very much experience in handling them. There have been occasions when the controller was unsure of the location of a particular GPS approach (S. Winter, personal communication, September 25, 1996). This alone is not a human factors interface design problem, rather it is a training and experience issue for the air traffic controllers. However, it does become problematic when the controller issues an instruction, such as changing to a different runway. This is time consuming using the GPS unit. Air traffic controllers need to be aware of the workload problems associated with certain instructions and that pilots may not respond immediately to their instructions because they are busy reprogramming the unit. Pilots need to be aware of how to handle any possible controller instruction that could be given during the approach.

Duplicate Approach Waypoints. For some approaches, the same waypoint may appear more than once. For example, the Aeronautical Information Manual (FAA, 1998) states that some approaches contain the same point for the initial approach waypoint, the final approach waypoint, and the missed approach holding waypoint (p. 1-1-49). It is important that the pilot be aware of which of these waypoints is currently active for the unit, as it can lead to an inappropriate sequencing during the approach. This can cause the pilot to become confused during a critical portion of the flight.

Missed Approach Problems. The Aeronautical Information Manual (FAA, 1998), also discusses possible problems with GPS receivers during the performance of missed approaches (p. 1-1-49). It states that if a pilot tries to activate a missed approach prior to reaching the missed approach waypoint, the unit will set the CDI sensitivity to ± 1NM and the receiver will not sequence past the missed approach waypoint. The pilot will have to perform the actions over again once the missed approach waypoint is reached.

CONCLUSIONS

As with the first paper in this series (Williams, 1999a) it is important, given the problems stated in this paper, that efforts are made to discover the frequency of occurrence of these problems and what their effects are on pilot workload and performance. A primary problem with most receivers is that they have a large number of available functions, but a limited number of controls for activating those functions. Also problematic is the manner in which GPS functionality is implemented. Different procedures are required for the same functions for every receiver on the market – even for units made by the same manufacturer.

The following solutions are offered for improving some of the problems mentioned in this paper and the previous paper (Williams, 1999a). It is doubtful that easy solutions exist. However, opportunities for GPS improvements are presented below for the FAA, GPS manufacturers, and the end users – the pilots.

FAA Opportunities for Improvement

One suggested solution to the problem of receiver complexity is to reduce the number of different kinds of GPS approaches that receivers need to accommodate. The elimination of overlay approaches containing procedure turns that require suspension of automatic sequencing of waypoints would eliminate some of the problems associated with this process. Most of the approaches requiring suspension of automatic sequencing are overlay approaches. Overlay approaches are approaches that were previously established VOR or NDB approaches that have been redefined by the FAA as GPS approaches. Steve Jackson, of the FAA Flight Standards Division, has suggested that "The GPS 'T' approach must be established as the standard for WAAS to maximize GPS receiver capabilities" (personal communication, February 18, 1998). Operationally, a "T" approach would normally eliminate the need to suspend waypoint sequencing (although there might still exist a need to place an aircraft into a holding pattern during this type of approach), and would likely reduce pilot workload during a high-workload portion of flight.

Manufacturer Opportunities for Improvement

Designing an "undo" function on all of these receivers would keep the pilot from becoming lost after making an entry error and reduce control inputs during critical phases of flight. Whether standards are imposed by the FAA, or volunteered by manufacturers, some standardization of button labels, annunciator panels, and displays is needed. At a minimum, a core set of GPS functions should be performed in essentially the same way for every unit on the market. John Steuernagle, of the Aircraft Owners and Pilots Association Air Safety Foundation, has recommended that standardized procedures be designed for the following set of GPS functions (J. Steurenagle, personal communication, February 3, 1998):

Selecting a waypoint
Establishing a course to or from a waypoint
Selecting and activating an approach
Transitioning to a missed approach procedure
Interruption of autosequencing.

Based on earlier findings, two items that could be added to this list are the re-activation of automatic waypoint sequencing, and the selection and activation of an approach to an alternate airport.

A second, though somewhat radical suggestion to the manufacturers is to reduce the functionality of the receivers. Anecdotal evidence suggests that most pilots use only a small amount of the GPS functionality on a regular basis. Removing extra functionality from the units would probably have little effect on the utility of the units. Whether or not it would affect sales is a separate issue. Manufacturers like to advertise a myriad of functions that a particular unit can perform. Removing excessive functionality in favor of simplifying the operation of the unit makes sense from a human factors standpoint, but if it makes the units less desirable than ones with more functionality, it will never happen.

Pilot Opportunities for Improvement

The Aeronautical Information Manual (FAA, 1998, p. 1-1-49) recommends that, before using any particular receiver for instrument flight, pilots should practice GPS approaches under visual meteorological conditions until thoroughly proficient with all aspects of their equipment (receiver and installation). The pilot should practice:

- Utilizing the receiver autonomous integrity monitoring (RAIM) prediction function
- Inserting a Standard Instrument Departure (SID) into the flight plan, including setting terminal Course Direction Indicator (CDI) sensitivity, if required, and the conditions under which terminal RAIM is available for departure (some receivers are not SID or STAR capable)
- Programming the destination airport
- Programming and flying the overlay approaches (especially procedure turns and arc)
- Changing to another approach after selecting an approach
- Programming and flying "direct" missed approaches
- Programming and flying "routed" missed approaches
- Entering, flying and exiting holding patterns, particularly on overlay approaches with a second waypoint in the holding pattern
- Programming and flying a "route" from a holding pattern
- Programming and flying an approach with radar vectors to the intermediate segment
- Indication of the actions required for RAIM failure both before and after the Final Approach Waypoint (FAWP)
- Programming a radial and distance from a VOR (often used in departure instructions).

In addition, Steve Winter, of the FAA Flight Standards Division recommends familiarization with the following additional procedures (S. Winter, personal communication, September 25, 1996):

- Recovering from flying past a waypoint where holding was intended, after failing to place the receiver in the hold mode
- Adding another waypoint prior to the Initial Approach Fix (IAF) waypoint after entering the approach procedure data into the flight plan
- Rejoining the course between two waypoints after being cleared and proceeding directly to another waypoint.

Pilots should never assume that familiarity with one GPS unit will facilitate learning to use another unit. During the course of the operational tests mentioned in this paper, there were several instances of pilots having difficulty transitioning to the units used in the test, despite familiarity with their own GPS units. Pilots should make certain that they are comfortable and proficient with the unit that is to be used for that flight. Also, pilots should not assume that a familiar type of GPS unit will interact with different avionics displays as expected, due to possible differences in installation procedures.

Finally, as was mentioned in the first paper, if a pilot becomes totally lost and unfamiliar with what is seen on the GPS display, he/she should have a backup procedure ready to implement. Pilots should realize that GPS units, as currently designed, are not intended to handle any and all navigation tasks. Appropriate use of the systems is both prudent and recommended. Lessons learned from advanced transport aircraft have shown that turning off automation is many times the best solution (Billings, 1996).

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