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GPS User-Interface Design Problems

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16. Abstract

This paper is 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. The paper focuses 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 layout and design of knobs and buttons; control labeling inconsistencies across units; the placement and use of warnings; feedback, or the lack thereof; and the integration of specific flying tasks while using the receivers. 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.

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GPS User-Interface Design Problems

INTRODUCTION

This paper is 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. No GPS products will be mentioned by name, since the aim of the paper is not to criticize a particular GPS manufacturer. Instead, the paper will 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 to be addressed involve the layout and design of knobs and buttons; control labeling inconsistencies across units; the placement and use of warnings; feedback, or the lack thereof; and the integration of specific flying tasks while using the receivers. 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.

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 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), as well as from an FAA technical report (Winter & Jackson, 1996). Finally, data were taken from observation logs from a recently conducted operational test of a GPS Wide Area Augmentation System (WAAS), and from personal observation from the WAAS test.

Human Factors Guidelines

Initially, the FAA Aircraft Certification Human Factors and Operations Checklist for Standalone GPS Receivers (FAA, 1995) was the primary human factors reference source for GPS receiver design. The human factors and operations checklist is hereafter referred to as "the checklist." The checklist is a useful source of human factors design guidelines and includes references to several other commonly used guideline documents from both the military and civilian sectors.

DESIGN PROBLEMS

The following design problems are not intended to be an exhaustive list. Many problems could not be included because of time and space constraints. Also, with the exception of complexity, the problems are not presented in order of importance since the importance of any particular 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 those determinations.

Complexity

Probably the most significant feature of GPS units, as far as the potential for user errors is concerned, is the sheer complexity involved in their operation. It is not that the manufacturers of these devices purposely designed units to be difficult to operate. Instead, the primary reason for their complexity is that they allow the performance of a large number of tasks using a limited number of controls and a small display area.

One indicator of the complexity of a GPS unit is the size of its instruction manual. Manuals of between 100 and 300 pages are common. In addition to the large number of tasks that can be performed by a GPS unit, there is a relatively small area for the display and the controls — the buttons, switches, and knobs — needed to access GPS functionality. For this reason, most of the controls serve to activate multiple functions.

Taken together, the large number of accessible functions and limited number of controls will lead to the inadvertent activation of unwanted functions. When this happens, the pilot may not be familiar enough with the display configuration to correctly recover from the mistake without accessing the operations manual. The end result is confusion for the pilot, increased head-down time, and possible airspace blunders. It is unlikely that anyone would be familiar with the entire operations manual for a particular device, and it is also unlikely that a pilot would be able to know what to do in every situation without referring to the manual. One possible fix for this problem is to require an "undo" button/function on the unit. This would allow a pilot to return to the previous display configuration and proceed with the intended operation.

Knobs and Dials

The following problems have been noted for more than one GPS unit currently used for instrument approaches.

Activation Feedback

The checklist suggests that all knobs and buttons should provide adequate activation feedback to the user. Although this suggestion is part of the checklist's bench test section, it is important that activation feedback be sufficient during flight, when noise and vibration are present. At least one of the units on the market provided no tactile or auditory feedback indicating that a button had been activated. There was no noticeable tactile or auditory feedback when pressing the button, and visual feedback occurred only after a delay, when the screen display changed. A lack of feedback can lead to multiple button presses and the activation of displays and functions that were not intended.

Button Placement

The checklist indicates that the risk of inadvertent activation or deactivation of GPS functions should be minimized. An example of a violation of this principle is shown in Figure 1 and concerns the placement of 3 buttons.

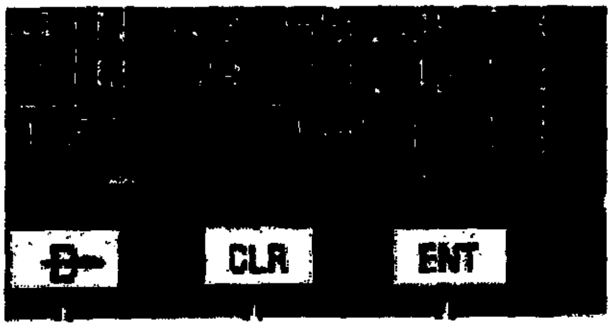

Figure 1: Example of poor button placement

The figure portrays a portion of the control interface of one of the more popular GPS units on the market. Three buttons are shown and located at the bottom of the display.

They include the "direct-to" (capital D with an arrow), "CLR" (clear), and "ENT" (enter) buttons. While performing an approach, if the pilot elects to execute a missed approach, the procedure for this GPS unit (and most others) is to push the "direct-to" button and then the "enter" button. The placement of the clear (CLR) button between the direct-to and enter buttons increases the likelihood of accidentally *pressing the clear (CLR) button during the execution of the missed approach procedure. In so doing, the* display changes to one that is not expected, leading to confusion about how to recover. Furthermore, recovery may require extensive reprogramming of the GPS unit. This would certainly add to the already high degree of stress involved in executing an unplanned missed approach. Maintaining a specified minimum altitude and course, while trying to reprogram the GPS unit, could create a visually and mentally overloading situation. Repositioning the receiver buttons is warranted, though again, one possible solution to this problem would be an "undo" button/function.

Knob Issues

Many of the GPS units reviewed required the use of a rotary-type knob to select the information required for an operation. One example is in the selection of airport identification codes. These codes consist of three or four alphanumeric characters of the form F28, KSTL, OKC, etc., that identify various airports, VORs, and other navigational waypoints. Some receivers do not allow the input to "wrap around" from A, back to Z, using a single counterclockwise turn. Instead, to go from A to Z, the user must dial forward (clockwise) through the entire list. Also, if the users inadvertently dial past the intended character, they must continue to dial forward through the list until again reaching the correct character. This arrangement leads to significantly increased head-down time while using the receiver, a problem that has been mentioned in recent GPS studies (Williams, 1998; Wreggit & Marsh, 1998).

A second major issue concerning the use of knobs is that some receivers allow the knob to be in one of two physical positions, either out or in. Pulling the knob out enables different functionality than when the knob is pushed in. Using the knob in the alternate position (pulled out) is not required to operate the receiver, and the pilot may not be aware that it functions in this manner. A serious problem with this arrangement is that it is difficult to know whether the knob is out or in without first testing it. None of the units provide an indication of the knob's position, such as a warning light, on the display. As one might be in the habit of performing a certain function with the knob at a particular point in a flight (for example, during the set up for an approach), it is unlikely that the correct knob position will be ascertained. The unit could fail to respond in the expected manner, leading to confusion and requiring a correction. Using a procedural checklist would avoid this type of error; however, referencing a checklist would significantly increase the head-down time of the pilot.

Labeling

Annunciator Variations

Some GPS units have an associated annunciator panel to provide indications of GPS status and satellite availability to the pilot. The annunciator panel, if used, is not necessarily co-located with the GPS unit and depends on room available on the cockpit instrument panel. If the annunciator panel is not located near the GPS unit, or the navigational instrument used during an instrument approach, there is a possibility that the pilot will miss critical information displayed on the various instruments.

Also, annunciator panels can be made by a third party manufacturer, so that the panel for a particular unit can vary from airplane to airplane. The labeling of GPS modes varied across the units reviewed. Figure 2 shows two of the several different GPS annunciator panels reviewed.

In particular, notice the third box of each annunciator panel in Figure 2, labeled unit A and unit B respectively. TSO-C129a (FAA, 1996), Par (a)(3)(xi)(2), states that, "The equipment shall provide the capability for accomplishment of holding patterns and procedure turns. Activation of this function shall at least: a. Change automatic waypoint sequencing to manual. ... d. Permit the pilot to readily return to automatic waypoint sequencing at any time prior to the designated fix ('TO' waypoint) and continue with the existing flight plan."

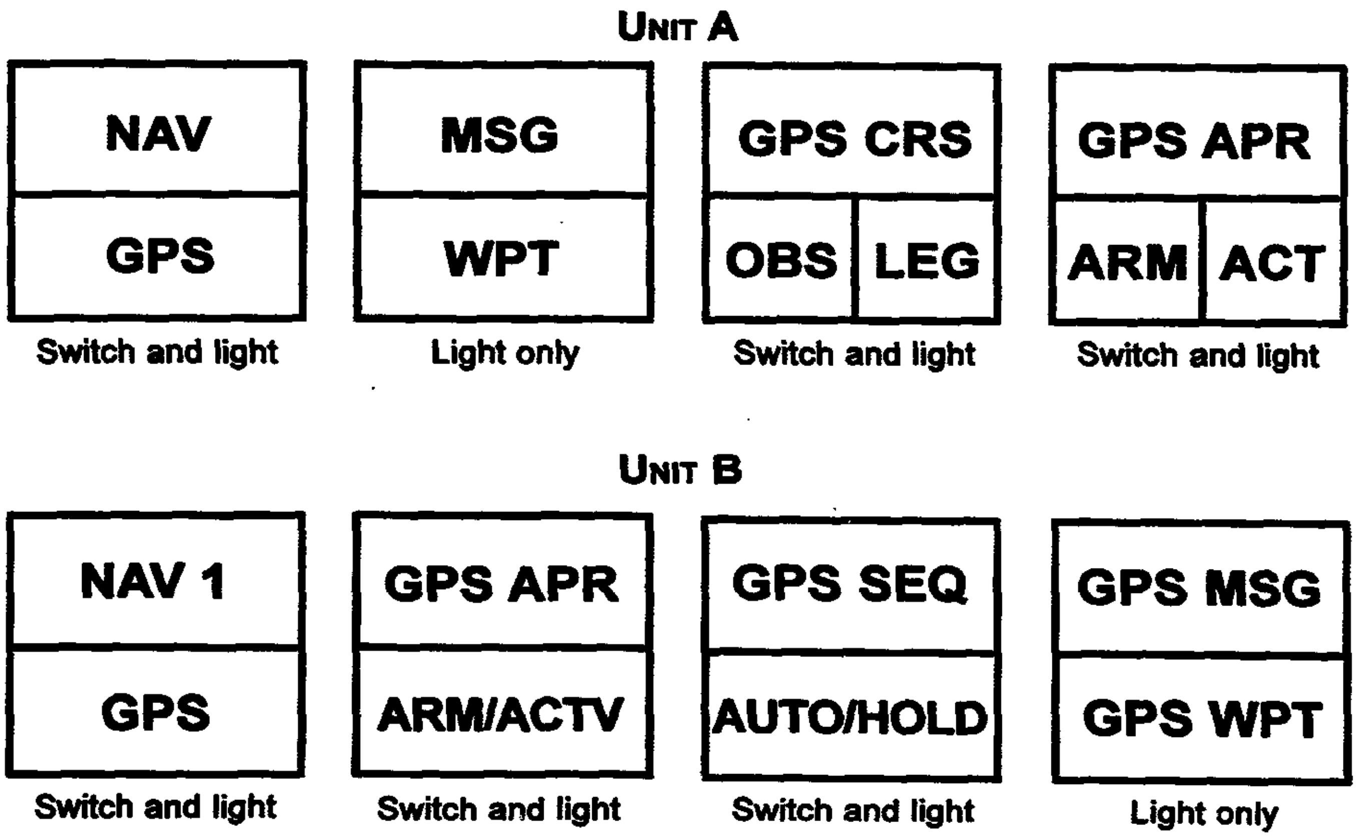

Figure 2: Two examples of annunciator panels

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For unit A, the annunciator button for manual interruption of autosequencing, for purposes of holding and procedure turns is called GPS SEQ, and includes two modes labeled AUTO and HOLD. Unit B labels their annunciator button GPS CRS, with the two modes labeled OBS and LEG. A third brand, not shown in the figure, does not have an external annunciator button and automatically enters the "hold" function when outbound on an approach and enters an "auto" sequence function when inbound. As will be discussed below, there can be confusion over the labeling and operation of a panel and receiver if a pilot is required to suspend and restart autosequencing.

Button Labels

The number and variety of buttons included on each GPS display is different for every unit on the market. In addition, buttons that perform the same type of task on different units can have different labels. Table 1 presents several popular brands of GPS units, along with a listing of the buttons and their labels that are present on each of the units.

In addition to the buttons listed, most of these units have one or two ganged knobs. A ganged knob consists of an outer, shorter knob, surrounding an inner, taller knob. As was mentioned earlier, the inner knob can be pulled out or pushed in to provide additional functionality for some of the units.

Keep in mind that all of the units reviewed provide essentially the same set of functions but require accessing specific functions in different ways. Some functions that are accessed through a knob on one unit may require a button press on a different unit. While most units have an "enter" (ENT) button to initiate a selection, Unit E in Table 1, for example, uses a button labeled ACK for this task. This lack of consistency and operational vagaries make it very difficult for a pilot to transition from one type of unit to another.

Procedural Problems

Selecting an Alternate Airport

The selection of an alternate airport requires many steps, since approaches can only be selected from the active flight plan and only one approach can be stored at one time. Approaches cannot be stored in inactive flight plans. The selection of an approach to an alternate is done after the decision to go to the alternate airport has been made. If the alternate airport is fairly close to the primary airport, very little time is available to accomplish the program change, as well as other required tasks. Many GPS units allow setting up a second flight plan. This feature could be used to establish a route to an alternate airport but not the approach itself. If the procedure for selecting a second flight plan is not often used, it might be difficult for a pilot to recall the details, should the situation warrant. Minimizing workload in this situation requires the pilot to be well rehearsed in the procedure beforehand. This advice, of course, holds for many of the problems discussed in this paper. The pilot could also program additional waypoints after the destination, if the receiver allows. However, as was determined during WAAS receiver testing (Winter & Jackson, 1996), some pilots do not take the time to input a complete flight plan into their GPS receiver, much less a flight plan plus additional waypoints to serve as an alternate destination.

Automatic vs. Manual Waypoint Sequencing

One of the most often cited problems occurring during the operational testing of these systems, to date, involved either placing the receiver in a mode where it automatically sequences from one waypoint to the next during the approach or in a non-sequencing mode. The non-sequencing mode is required for many overlay-type approaches (and some stand-alone approaches) in which a procedure turn, or hold-in-lieu-of procedure turn, is accomplished before

Table 1: Button Labels for GPS Units

Unit	Number	Labels
A	7 buttons	CRSR (2), MSG, ALT, D->, CLR, ENT
B	10 buttons	CRSR, MSG, D->, CLR, ENT, NRST, SET, RTE, WPT, NAV
C	9 buttons	MSG, D->, ENT, WPT, NAV, FPL, CALC, AUX, APT/VOR
D	10 buttons	MSG, EMG, NAV, DB, FPL, SYS, D->, SEL, INFO, ENT
E	6 buttons	CRSR (2), D->, ALRT, MSG, ACK

establishing the aircraft on the final approach. In recently completed operational tests of these receivers (Winter & Jackson, 1996), it was reported that subject-pilots frequently forgot to take the GPS receiver out of the "hold" function after completing the procedure turn. Pilots were often unable to proceed to the next approach fix because the receiver was still in the "hold" function, and the pilot was often unable to determine the problem. Usually, the safety pilot had to prompt the subject-pilots about the failure, so as to prevent them from flying about aimlessly. Pilots were also sometimes unable to suspend autosequencing because the unit had already sequenced to the following waypoint before the pilot had taken the required actions.

Other testing found that the procedure for suspending and re-establishing automatic waypoint sequencing differed from unit to unit. For many of them, a button or switch on the annunciator panel was used to suspend and renew sequencing; however, for one unit, suspension and re-establishment of waypoint sequencing was primarily automatic. While this generally decreased pilot workload, if the pilot was required to suspend waypoint sequencing with this unit, the complex procedure was as follows:

- Press the direct-to button;
- Turn outer knob one click counterclockwise;
- Turn inner knob until proper course is selected;
- Press direct-to button again.

To then re-establish waypoint sequencing, the pilot was required to press the direct-to button twice. In addition to being non-intuitive, this procedure demonstrates the use of a button to accomplish a function for which it was not labeled and not originally designed.

Inconsistent Functionality

One final human factors problem to be discussed concerns differences in the way each GPS receiver functioned, depending on how it was installed in the aircraft. One example is found with the auto-slewing function for receivers connected to a horizontal situation indicator (HSI) used during a Distance Measuring Equipment (DME) Arc approach. GPS receivers can be installed in such a way that the HSI will automatically slew from one heading to the next during the execution of an approach procedure. A different installation with the same GPS unit will result in a configuration requiring the pilot to manually dial in new headings on the HSI while executing the same approach procedure. In this configuration, the GPS unit will present a message to the pilot each time a new heading should be selected. One possible scenario for pilots who rent aircraft is a situation in which they are given an identical airplane, with identical GPS equipment, but the instruments behave differently during the approach because of differences in the way the equipment was installed. In this situation, it may be difficult to determine if the aircraft has auto-slewing capability until after it is airborne.

A second example concerns the selection and de-selection of the GPS unit during an approach. Some receivers automatically de-select the GPS unit when an Instrument Landing System (ILS) frequency is dialed in to the navigation radio. Under this condition, the ILS display is receiving its information solely from the ILS ground station. For other receivers, the GPS signal is not de-selected unless it is done manually by pushing a button on the annunciator panel. Whether the de-selection is automatic or manual is determined solely by the installation of the GPS unit.

A situation can arise where the pilot believes that the GPS has been de-selected when it has not. This will result in a case in which the glide slope indicator on the ILS display is controlled by the ILS signal, but the course indicator on the same display is controlled from the GPS.

CONCLUSIONS

This paper was not intended to be overly critical of GPS manufacturers or currently used GPS equipment. However, 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. As was stated in the introduction, the 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 some units made by the same manufacturer.

It is doubtful that easy solutions exist for all of the problems mentioned in this paper. However, opportunities for GPS improvements are presented below for the FAA, GPS manufacturers, and the end users – the pilots.

FAA

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 approaches (overlays and GPS approaches containing procedure turns) that require suspension of automatic sequencing of waypoints would eliminate the need for the extra functionality required to accomplish this task. 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 to maximize GPS receiver capabilities" (personal communication, February 18, 1998). Operationally, a "T" approach would eliminate the need to suspend waypoint sequencing, and would likely reduce pilot workload during a high-workload portion of flight.

Manufacturers

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 Airplane 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 findings stated earlier, 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.

Pilots

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 all avionics displays as expected, due to possible differences in installation procedures.

Finally, if a pilot finds himself/herself totally lost and unfamiliar with what is seen on the GPS display, they should have a backup procedure ready to implement. If all else fails, pilots should be prepared at any time during the flight to simply turn the unit off. They shouldn't follow their GPS unit into the ground.

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