Analysis of Adverse Events in Identifying GPS Human Factors Issues

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Abstract

The purpose of this study was to analyze GPS related adverse events such as accidents and incidents (A/I), Aviation Safety Reporting System (ASRS) reports and Pilots Deviations (PDs) to create a framework for developing a human factors risk awareness program. Although the occurrence of directly related GPS accidents is small the frequency of PDs and ASRS reports indicated there is a growing problem with situational awareness in terminal airspace related to different types of GPs operational issues. This paper addresses the findings of the preliminary research and a brief discussion of some of the literature on related GPS and automation issues.

Introduction

The advent of new technologies in the cockpit was once expected to reduce workload and improve safety by providing all the information a pilot could want in one small package. The efforts of the navigation flight computer industry, with limited space on an aircraft panel and great imagination in packing avionics, have lead to an extensive array of user interface designs. The equipment gives pilots tremendous flexibility through the proliferation of functions and options for accomplishing tasks.

Much is being written about the lack of standardization of these new user-interface designs being produced in spite of FAA guidelines to the contrary (Wright, 1998). With increased production, per unit costs have dropped, making GPS equipment affordable for the General Aviation (GA) sector.

Automation can have a dark side, induced by lack of familiarity and system complexity that can lead to a general lack of situational awareness, competition for attentional resources during high workload periods and false security in the accuracy of the data base (Sarter and Woods, 1995). Orlady and Norman (1988) note that automation introduces new types of errors and breakdowns especially when a crew is inadequately trained in its use of the automated system. Although, this paper focuses on general aviation (GA), an example of automation error which has implications for the GA industry bears noting -- the American Airlines accident in Cali, Columbia.

On a nighttime approach into Cali, Columbia, an American Airlines crew selected an identifier and retrieved information from their database regarding, what they believed to be the navigational beacon for the airport. Unfortunately, the airport shared the same identifier as another beacon close by (NTSB, 96, Gerdsmeier, Ladkin and Loer, 1997). Unable to recover through reprogramming the FMS or taking evasive action when the aircraft suddenly banked toward the other beacon, the aircraft hit the terrain, killing all on board.

The importance of this accident is the nature of the error. Unlike many general aviation pilots, the American pilots were frequent users of the equipment and received recurrent training on their use. This accident was the result of a data base error and lack of pilot situational awareness -- both problems being experienced by today's pilots, airline and GA.

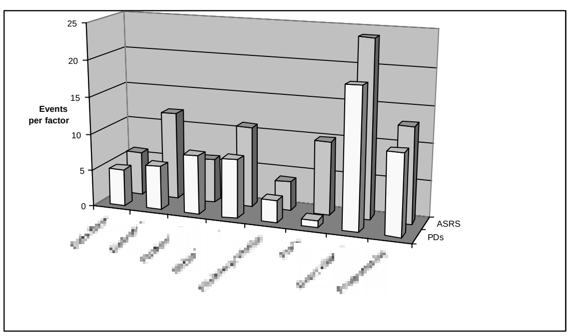
Event Databases

In order to get a snapshot of the problems pilots are encountering in today's airspace system, several of the databases maintained in the National Aviation Safety Data Center (NASDAC) were examined. In many cases, the difficulty with examining these types of records rests with the investigator's inability to inter-view the pilot to determine which aspects of GPS usage lead to the problem. The following discussion briefly discusses the number and types of events. This is followed by a more detailed listing of specific problems that occurred across all the databases

Accidents/Incidents: There were 58 accidents and incidents from 1990-99, where GPS was in the narrative. However, only 10 of these accidents or incidents could be considered GPS related. These accidents included lack of familiarity with GPS, distracted while programming leading to approach to landing crash in the trees and another accident where the pilot was programming a flight plan and climbed into another aircraft.

Pilot Deviation Reports (PDs): Pilot deviations represent transgressions from assigned course, penetration of controlled airs-pace – both civil and military, and deviations from air traffic control directives. Frequent transgressions resulting from GPS utilization were found in the Pilot Deviations database but were still insufficient in narrative content to identify real usability issues.

Sixty-one records implicating GPS were found and divided into 8 categories: database error, distracted while operating GPS, GPS malfunction, lack of knowledge, misinterpretation of Data, mode error, over reliance on GPS, and programming error. Figure 1 illustrates the frequencies of each category of the pilot deviations.



Aviation Safety Reporting System (ASRS): ASRS has put together a report on GPS events. ASRS interviews with pilots provide more detailed information than the PD reports. This document identified 130 reports where the term “GPS” was in the narrative. Of these 86 (66%) reports were determined to reflect problems with usage during flight.

The graph below compares the event raw data between the pilot deviations and the ASRS reports. Generally, both databases reflect problems falling into similar categories at comparable levels.

The following is a discussion of some of the more commonly experienced events associated with GPS utilization that are shared by all event databases.

Over-reliance on GPS:

- pilots took for granted the accuracy of the information
- pilot had committed mental resources to GPS, forgot about VOR or NDB backup.
- two pilots followed database fixes rather than ATC assigned way-points
- Expectation of alerts and/or moving maps to provide
- lost signal in remote area, got lost.

Database Errors:

- data cards had not been updated,
- did not contain the fix or facility,
- old frequencies on new cards or
- out of calibration

Programming Errors:

- input wrong latitude and longitude for intersections, or wrong fixes
- programming of units while airborne rather than set up flight plan on the ground.
- Caused altitude deviations and airspace violations while trying to reprogram, or gain situational awareness.
- Programming aircraft on approach and climbed into aircraft

Distracted While Operating GPS:

- lost satellite, tried reprogramming GPS
- battery dead on the hand held GPS
- flew into weather and tried to reprogram the computer to get out of the fog.
- engrossed in recovering from errors at the expense of piloting their aircraft.
- aircraft rolled forward into the runway as pilot forgot to maintain brake pressure while distracted by programming GPS
- distracted on approach, hit trees
- engrossed in recovering from errors at expense of piloting aircraft.

Malfunctions: Whether the events that occurred resulted from actual malfunctions or a rationale for being off course could not be determined. Installation error or when GPS quit were cited as malfunctions.

Lack of Knowledge:

- Problem areas in flight planning (airborne) programming instrument approaches, looking for airport, waypoint or VOR information; confusion with knob or button labeling, inputs errors.

Misinterpretation:

- pilots did not understand information on their moving maps or text display.
- Lost on final, perceived aircraft to be above, below or outside controlled airspace.

Mode Error:

- selecting GPS mode rather than localizer for H.S.I. to execute the approach.
- forgetting to switch from GPS to VOR/Localizer
- Lost display during mode switching.

Other issues that bear noting involve direct-to functions and hand held (HH) GPS units:

Abuse of the “direct to” function:

- inadequate preflight planning to determine what was in between point A and point B
- pilot narrowly missed obstacles that were in the flight path.
- pilot penetrated ADIZ while flying coastal routes.

Hand held GPS: positive and negative attributes.

- benefit as backup when other nav systems fail
- unsecured units falling off of lap, seat, panel.
- batteries fell out during use.
- dead batteries
- unit caught on DG knob impeding controls
- unit fell on floor jamming controls on takeoff
- pilot used a hand held GPS for navigation through narrow pass in IMC (instrument meteorological conditions);
- pilot got lost using hand held GPS for instrument navigation and had to reprogram waypoints

Complaints registered by pilots in the report also included the need for verifications, lack of feedback, too much feedback, no error checking or advice, lack of prompting and disorganized page sequences.

Comparison of navigation systems.

GPS units allow a pilot to go from point A to point B by-passing the wandering VOR network across the country. While getting to the destination can be more efficient, executing a simple approach can be more complicated.

There are 13 steps in a GPS approach compared to 5 under the traditional system. The task starts just prior to ending the enroute phase of flight. Typically, an instrument approach has an “initial approach fix” (IAF), a final approach fix (FAF) and a “missed approach” (MAP) where, the pilot(s) executes a “go around” if the airport is not in sight or the landing is unsafe. If the pilot forgets to activate the leg, the flight plan will not sequence through the fixes and the programmed route from the last fix can become inaccessible. Unless a pilot has trained and/or experimented with these peculiarities, there will be no knowledge of the problem until it occurs.

Usability

Several studies have examined the usability of the receivers. Six TSO-C129A1 certified receivers were evaluated (Donovan, Huntley, and Turner, 1996) by pilots at the Transportation System Center in Cambridge, Massachusetts. Factors such as workload, pilot memory requirements and control actions to perform procedures were recorded. Problematic procedures generally were common across the six receivers. This study evaluated receiver usability and workload a variety of procedures.

The characteristics identified as problematic included: button labeling, text message, size, color, display of key information, moving map automatic scaling and documentation format. These were determined by recording the number of control actions per maneuver, whether prompts or button illumination was used to indicate to a pilot what actions were to be taken next, use of the cursor, changes in receiver modes, mode annunciation, use of multiple pages, pilot memory requirements, likelihood of errors, and pilots ratings of workload.

Four tasks were consider to be easy to perform: flying directly to a waypoint, flying directly to an airport, selecting and flying an approach or creating and editing a flight plan(in most cases). Six were cited as having medium or high workload: 1. vectors to intercept final approach course, 2. missed approach with a vector or heading to intercept a course to a MAP waypoint, 3. diversion to an alternate, 4. DME arc approach, 5. Intercept a parallel offset base, 6. Return to departure airport.

For example, for the six receivers, control inputs to: create a flight plan - 15 to 21, intercept a parallel offset 12-19, to edit a flight plan - 14 to 19 and 6-19 to select an approach, and programming different approaches - 6 to 21 control actions. Three receivers automatically provided guidance for short-leg course reversal while the other 3 ranged from 5 to 19 inputs for the same task. In 2 cases, the evaluators were unable to determine how to conduct a parallel offset to a route.

The researchers suggested that the physical configuration of the controls – positioning, size and shape of the buttons – encouraged accidental activation.

On receivers where the enter and clear buttons are adjacent to each other, the problem can in an accidental clearing of an active approach or screen.

Labeling presented problems of function confusion or inconsistency. In some cases, inner and outer knobs were not positioned so that the user could clearly determine their different functions. As an example, SEL, for select, was used in one receiver for editing rather than a straightforward EDIT. CLR buttons not only deleted flight plans but also were used for cycling through fields and selecting controlling frequencies. The ENT button that is typically used to confirm inputs or complete an action, in some cases, initiated an action or activated a flight plan.

Message content and appearance was found to be difficult for users to understand or interpret, impairing the pilot's ability to determine the relevance of the message to operations or to the action required. Short duration of a displayed message also prevented pilots using one receiver from noticing a critical message and the message could not be recalled.

Transport Canada (Heron, Krolak and Coyle) looked at the architecture of a GPS operational system, creating a flow chart of the controls, primary pages, and their respective subpages. Their study also cited inconsistency from one receiver to another of control usage, key strike errors, memory load, non-intuitive logic, and confusing messaging. Noted in two of the studies was information with regards to the "Hold" button that maintains the heading on the HSI but not the heading to the next waypoint. The hold button must be released before advancing to the next waypoint. The pilot's ability to remember this in high workload conditions coupled with the incompatibility with traditional navigation procedures may render GPS rules irretrievable. Finally, "hold" also is traditionally associated with the ATC command terminology and procedure to execute a holding pattern and may cue the pilot to use that control to perform the maneuver.

Heron, et .al. suggests that even a well-trained pilot's memory is taxed after having been absent from flight duty of only a few weeks. These errors are more pronounced during high stress, fatigue and workload situations as well as when pilots operate different receivers in different aircraft. Researchers assert that switching receivers with operational differences results in disorganization as well as negative transfer.

<u>Hand Held Receiver Evaluation</u>

Hand held receivers are generally for VFR use but that has not stopped pilots from catastrophically using them during IMC. Elliot (1996), in a similar examination of seven portable receivers, cited logic as a problem. He also found hand held receivers had poor or non-existent key set illumination that would preclude unaided night operations and readability problems due to side-angle viewing. Numerous incidents involved hand held receivers, and researchers have stressed the importance of containment of batteries and accessories for power so that they do not jam controls or distract the pilot. Ergonomically, units held in the lap or tethered to the leg can cause discomfort from heating and weight.

Potential for Errors:

Human-automation interaction is gaining in attention due to the potential for errors in dynamic event driven and process control environments (Mouloua & Koonce, 1996). A survey of pilot's attitudes toward automation, in general, revealed that automation requires "self discipline" because it makes things too easy (Rudisill, 1995). The potential for traps leading to accidents or incidents was a critical concern of the respondents.

Research (primarily on airline operations) on mode awareness and automation error is expanding with the use of GPS and FMS systems. Studies cite a pilot's inability to navigate through modes without getting lost as a major problem that compromises primary task accomplishment (Sarter & Woods, 1995).

The GA community uses any type of GPS that it can afford based on the type of operation it can conduct from hand held to panel installed equipment. The cost of equipment depends on navigation capability, data base quality and frequency of updates, accuracy and market economics. The lower-end models often have many of the same capabilities of the expensive units except they may not be certified for IFR use.

A general analysis by Kevin Williams (1998) at the Civil Aeromedical Institute, and Adams, etal (1993), pull together many of the problems that have been cited in the past. Williams noted two areas where GPS equipment fails in its ability to deliver information and provide guidance: design and procedures. Design problems include system complexity, display and character size, colors and contrast, inadvertent activation of unwanted functions, multiple activation of single control knobs, knobs vs. buttons functionality, placement, labeling and feedback.

Other researchers cite reliance on automation to perform tasks and make decisions as an emerging issue. This "automation bias" leads to "automation errors" where pilots take inappropriate action because they over-attend to performing functions related to information retrieval and navigation set-up, task related inputs or attempting to understand directions. This was illustrated in several PDs where pilots attended to failure mode recovery, performing initial programming or were required to reprogram while airborne. Also "automation omission errors" occur when errors are made when pilots fail to react because the automated aids do not inform them of a potential problem (Mosier, Skitka & Heers, 1995).

In summary, most studies cited common problems with similar results noted above but the lists of automation issues appear to keep growing. Table 2 below cites those common factors identified which produce errors and undermine familiarity with GPS avionics. The event data bases discussed in the preceding section do not provide this level of data and therefore are not included in the problem analysis.

Training

There are two classes of users of GPS equipment in the GA sector: aircraft owners or employees (including corporate and many air taxi pilots) and aircraft renters. Aircraft owners have the benefit of continuous use of their equipment. Owners can train on the unit at home referencing the user's manual or a PC based simulator. Renters will have had little experience with the avionics or exposure to training materials. In cases where system rules have been tested after an absence, it was determined that although practice can routinize procedures, irregular usage or different equipment can lead to errors in operation and add stress during high workload tasks.

Training should enrich a pilot's understanding of his/her technology and have positive effects on the pilot's sense-making. It should help reduce the ambiguity of operating a GPS. Training on avionics is a function of the knowledge of the instructor or the instructional method, the availability of user's manuals and ability of the pilot or renter to training on the ground with the unit itself or with simulators. Every unit has a modicum of capability for training but the thoroughness varies and human factors issues are usually not addressed. Videos and PC simulators focus on using the equipment and conducting approaches, while hand held receivers typically allow the pilot to "free-play" with the unit.

The multiple events analysis detailed above represents the first step in a needs assessment for developing training materials.

Training Inventory

Most GPS manufacturers produce either a PC based simulator or have accessories that allow for tabletop flying of a GPS unit. To determine the breadth of seminars or self-paced training available, an inventory was conducted. Human Factors is not considered by most of the manufacturers training modules but is cited in one of the generic "how-to" videos and AOPA's seminar on "Tricks and Traps." AOPA also provides a web site with links to GPS manufacturers' websites, many of which provide owners manuals and free simulators with which pilots can interact and learn the different makes and models of GPS avionics. The FAA, recognizing limitations and deficiencies in information and training materials has initiated the production of human factors videos and CDs for inspectors and pilots.

Conclusions and Recommendations

Looking at existing data, the errors that have occurred can be divided into the following simple classifications: pilot-centered, operational and equipment design.

- Pilots-centered: GPS specific and general automation issues such as complacency, info/display misinterpretation, misperception, mode confusion, misunderstanding of system integration, input errors, improper use of system.
- Operational: pilot experience with equipment, training and systems understanding.
- Equipment design: inconsistent, confusing controls, labels, inadvertent operation and control size, shape and location.

These general categories will serve as the foundation for conducting research and developing training programs to help pilots better understand their GPS units, how to access training and the value of maintaining proficiency. Important issues investigate include the following:

- Conducting a more detailed needs assessment
- Situation identification of judgment or performance errors for scenario-based training

- Learning and coping techniques for failure modes during both VFR and IFR operations.
- Survey pilots to understand more about the characteristics of self-paced learning.
- Identify information dissemination tools such as point of sale delivery, screen savers, brochures, videos, interactive CBT and other common methods that can reach all pilots.

Currently, the adverse events that have occurred provide industry and government with an indication of potential problems with the growing use of GPS. The suggested efforts that are directed at educating pilots of the benefits and potential problems associated with GPS navigation should help improve their awareness of how to use their systems both safely and efficiently.

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