2007

The Effects of GPS and Moving Map Displays on Pilot Navigational Awareness While Flying Under VFR

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Stephen M. Casner
NASA Ames Research Center
Mail Stop 262-4, Moffett Field, CA 94035-1000

GPS and moving map displays are popularly believed to increase pilot navigational awareness – further empowering the already aware pilot with additional information about their position and surroundings. In a first experiment, pilots' beliefs about their own navigational awareness were compared to their measured awareness while navigating along a cross-country route. The results demonstrate a familiar out-of-the-loop effect and a marked disparity between what pilots believed and how they performed. In a second experiment, different pilots were asked to more actively participate in the navigation process while performing the same navigational task. The results indicate that this additional involvement significantly improved pilots' measured awareness. Overall, the results call into question unqualified beliefs about GPS, moving maps, and navigational awareness, and highlight the need for pilots to understand the potential human factors pitfalls associated with advanced cockpit systems.

Introduction

GPS and moving map displays are often claimed to increase pilots' navigational awareness. These claims are partly justified by some obvious advantages offered by GPS and moving maps. One only need consider the problem of locating the nearest suitable airport in the event of an emergency. GPS receivers pinpoint the position of the aircraft while moving maps quickly help identify the best course of action. During this type of emergency, it is hard to imagine a more timely and useful information resource.

Empirical studies have demonstrated a cost associated with not having to actively perform mental calculations and discriminations that are made automatically by a computer. Memory and awareness of information that is passively monitored has been shown to be significantly poorer than information that human operators generate themselves using mental problem solving and rehearsal [Slamecka and Graf, 1978; Glenberg et al, 1977; Craik and Lockhart, 1972]. Observational studies of humans working with automation, in the aviation domain as well as others, have demonstrated poorer awareness among human operators who perform tasks with the assistance of automated systems [Uhlarik and Comerford, 2002; Endsley, 1996; Endsley and Kiris, 1995; Parasuraman, 1987]. These studies draw a common conclusion: in an effort to make the human operator more aware by providing more information through automation, we sometimes make the human less aware.

Experiment 1

This experiment aimed to measure pilots' beliefs about their own navigational awareness when using GPS and moving map displays, and to compare those beliefs to an objective measure of navigational awareness.

Participants

Sixteen pilots who had basic familiarity with GPS receivers and moving maps participated in the experiment. All pilots reported that they did not have significant familiarity with the geographical area in which the data were to be collected.

Apparatus

The experiment airplane was a Diamond DA40 (Diamond Star) equipped with a panel-mounted GPS receiver and a color moving map display. All pilots were furnished with a current San Francisco sectional aeronautical chart that covered the area through which the experimental flight was conducted. The experimenter had access to an additional GPS receiver that was hidden from pilots' view.

Procedure

The sixteen pilots were told that they had to complete a cross-country flight that consisted of a series of nine checkpoints. It was explained that the first three checkpoints were intended as practice checkpoints as pilots made their way out to a circuit of six additional checkpoints, located in an unfamiliar area, that were of interest to the experimenter. The last six checkpoints formed a closed circuit over which the data were to be collected. The most distant checkpoint was approximately 105 nautical miles from the origin airport.

Pilots were instructed to fly as closely as possible to each checkpoint, and to report when they believed that they were directly over each checkpoint. Pilots were briefed on the route prior to engine start at the origin airport. A sectional aeronautical chart was used to point out the route including each of the nine checkpoints.

Pilots navigated between all nine checkpoints along the flight in one of two different ways.

Eight pilots were randomly assigned to the Pilotage group. These pilots were given a San Francisco sectional aeronautical chart and were told that they would have to navigate by means of pilotage. Pilotage is a technique in which the pilot must find his or her way by correlating geographical features depicted on a chart with geographical features seen out the window of the airplane. These pilots were not permitted to use timers, calculators, plotters, or any other device that could facilitate navigation techniques other than pilotage (e.g., dead reckoning).

Eight pilots were randomly assigned to the GPS/Moving Map group. These pilots were given the same San Francisco aeronautical chart, but also used a panel-mounted GPS receiver that featured a moving map display. It was verified that each pilot was familiar with the basic features of the GPS and moving map prior to departure. The route consisting of all nine checkpoints was programmed into the GPS prior to takeoff.

Upon departure, pilots were asked to verbally estimate their navigational awareness in two different situations: (1) navigating using only a sectional chart; and (2) navigating using a sectional chart and a GPS receiver with a moving map display. Note that each pilot in each group rated themselves in the situation in which they were currently flying, and in the situation experienced by pilots in the other experimental group. Pilots estimated their navigational awareness using a 0-to-10 scale: 0 representing a total lack of awareness, and 10 representing perfect awareness.

All sixteen pilots flew over the nine checkpoints as instructed. All pilots were asked to announce when they believed they had reached each checkpoint. Upon each pilot report, the experimenter used a GPS receiver, hidden from the pilot's view, to note the actual distance from the checkpoint. This measure represented the pilot's navigational error.

Upon reaching the last checkpoint in the circuit, the experimenter intervened and announced a revision to the original plan for the flight. Instead of returning home, all sixteen pilots were asked to once again fly the circuit consisting of the previous six checkpoints, only this time, without any navigation resources available to them. In the case of the Pilotage group, the experimenter took away the sectional chart. In the case of the GPS/Moving Map group, the experimenter took away the sectional chart and turned off the GPS and moving map display.

After the first checkpoint, the experimenter again asked each pilot to rate their own navigational awareness in the current situation: flying with no navigational resources other than any knowledge about the area and airspace that they had collected during the first time over the checkpoints.

The sixteen pilots flew over the loop of six checkpoints once again, reported crossing each checkpoint, while the experimenter again noted the navigational error at each checkpoint.

Results

Navigation Error. The mean navigational errors for the two groups of eight pilots during the first pass through the circuit are shown in Figure 1.

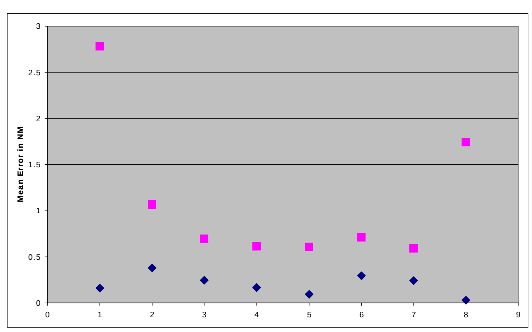

Figure 1. Navigational accuracy with all navigational resources available.

The mean navigational error and standard deviation for the Pilotage group was 1.1 NM (1.5 NM), while the mean and standard deviation for the GPS/Moving Map group was 0.2 NM (0.3 NM). Although the means for both groups fell well within the general 3 NM navigation standard for pilotage and dead reckoning cited in the Private Pilot Practical Test Standards [FAA, 2002], the GPS/Moving Map group achieved a significantly higher degree of navigation accuracy, $t = 3.74$, $p < 0.01$.

The mean navigational errors for the two groups of eight pilots during the second pass through the circuit, when pilots had no navigation resources available to them, are shown in Figure 2.

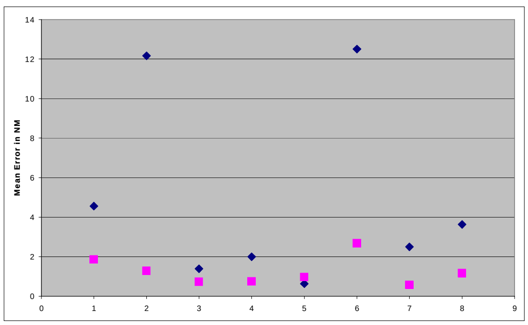

Figure 2. Navigational accuracy with no navigational resources available.

The mean navigational error and standard deviation for the Pilotage group was 1.3 NM (0.7 NM), while the mean and standard deviation for the GPS/Moving Map group was 4.9 NM (7.9 NM). Again, there was a significant difference between the two groups, only this time the situation was reversed: the Pilotage group performed significantly more accurately ($t = 2.17$, $p < 0.05$).

Error measures and statistics aside, there was a categorical difference in performance between the two groups. All eight pilots in the Pilotage group performed within the 3 NM minimum standard suggested in the practical test standards, while only one-half of the pilots in the GPS/Moving Map group met the standard. Regardless of how one chooses to statistically consider the two large average errors shown in Figure 2, these two cases have a practical significance. These two pilots were wholly unable to find their way back to point where they started, reporting this checkpoint to be 25 NM and 41 NM away from its actual location.

Self-Ratings of Navigational Awareness. Every pilot was asked to rate their navigational awareness in three different situations:

1) Prior to traversing the circuit of checkpoints, every pilot was asked to rate their navigational awareness in the situation they were currently flying. That is, the Pilot group was asked to rate their awareness when using a sectional chart, while the GPS/Moving Map group rated their awareness when using a GPS, moving map, and sectional chart.
2) Prior to traversing the circuit of checkpoints, every pilot was asked to rate what their navigational awareness would be if they were flying in the other experimental condition. That is, the Pilotage group hypothesized what their awareness would be if they had the GPS and moving map available, while the GPS/Moving Map group rated themselves using only a sectional chart.
3) While traversing the circuit of checkpoints for the second time, every pilot was asked to rate their awareness in their current situation: with no navigational resources available.

Table 1 shows the navigational awareness ratings given by pilots in both groups.

Table 1. Subjective self-estimates of navigational awareness

	Using Pilotage	Using GPS/Moving Map	Using Neither
Pilotage Group	7.625	9	8.125
GPS/Moving Map Group	6.625	9	4.875

Pilots in both groups rated awareness to be significantly greater when a GPS and moving map were being used ($t = 3.47$, $p < 0.01$). The interesting result is the significant difference between the two groups when they were confronted with the task of flying the circuit for the second time, with their navigation resources taken away. Pilotage group pilots rated themselves significantly higher than the GPS/Moving Map group pilots, and these ratings matched their performance. The GPS/Moving Map group pilots not only rated themselves significantly lower than the Pilotage group pilots ($t = 3.38$, $p < 0.01$), but also significantly lower than themselves when flying with the GPS and map display available ($t = 4.25$, $p < 0.01$).

Experiment 2

One interpretation of the results from Experiment 1 is that the observed drop in pilot navigational awareness was due to the passive role assumed by pilots when using equipment that automates the navigation task. This second experiment aimed to directly test that hypothesis. In this second experiment, different pilots were asked to perform the same navigation task while performing an additional task that required them to be more actively engaged in the navigation process. This additional task was to ask pilots to point out geographical features of interest as they made their way between the checkpoints. The research question is whether or not this additional involvement would result in improved performance when pilots were surprised with the task of navigating around the circuit with no navigational resources available.

Participants

The same criteria used in the previous study were used to recruit additional eight pilots. All pilots reported that they were wholly unaware of the earlier study about pilot navigational awareness.

Apparatus

The same Diamond DA40 (Diamond Star) airplane and sectional chart were used for this experiment.

Procedure

As with the first study, the data were collected in Northern California, during July and August, under VFR conditions with a reported visibility of greater than six statute miles at all nearby airports. Prior to engine start, pilots were told that the flight would require them to navigate along a series of nine cross-country checkpoints. Pilots were instructed to fly over each checkpoint as accurately as possible, and to report when they believed that they were directly over each checkpoint. Pilots were free to choose altitudes appropriate for VFR flight at their discretion. All eight pilots had available a sectional chart and a GPS with a color moving map display. The experimenter confirmed that each pilot was familiar with the basic features of the GPS and moving map prior to departure. The series of nine checkpoints was programmed into the GPS prior to takeoff.

En route to each checkpoint, pilots were asked to choose and point out three geographical features of interest. Pilots were told that they did not have to know anything about the geographical features they pointed out, or look up any information about them.

As pilots reported reaching each checkpoint, the experimenter used a second GPS receiver, hidden from the pilot's view, to record the true distance from the checkpoint.

After completing the circuit of six checkpoints, the experimenter took away the sectional chart, turned off the GPS and moving map, and (unexpectedly) asked each pilot to fly the circuit of six checkpoints again.

The eight pilots flew over the loop of six checkpoints once again, reported crossing each checkpoint, while the experimenter again noted the navigational error at each checkpoint.

Results

The purpose of the present study was to measure the effect of pointing out geographical features of interest on navigational awareness. For this reason, the results for this group of pilots are compared to the two groups from the first experiment. Thus, the analyses below present data for three groups:

(1) Pilotage: Pilots who used sectional charts only [from Experiment 1];
(2) GPS/Map: Pilots who used sectional charts, GPS, and moving maps [Experiment 1];
(3) GPS/Map with Callouts: Pilots who used sectional charts, GPS, moving maps, and pointed out geographical features of interest.

Navigation Error: *First Pass*. The graph in Figure 3 shows the mean navigational errors during the first pass through the checkpoints for the three groups of pilots.

The mean navigational error and standard deviation for the three groups were: Pilotage =

1.1 NM (1.5 NM); GPS/Map = 0.2 NM (0.3 NM); and GPS/Map with Callouts = 0.13 NM (0.7 NM).

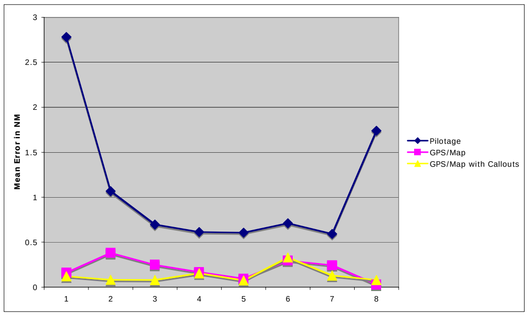

Figure 3. Navigational accuracy with all navigational resources available.

During the first pass through the circuit, with all navigational resources available, the group that pointed out geographical features was statistically indistinguishable from the GPS/Map group in the previous study that did not point out geographical features. The GPS/Map with Callouts group performed as well as the GPS/Map group, and significantly better than the Pilotage group ($t = 3.48$, $p < 0.01$), although all three groups performed within the 3 NM navigation standard cited in the Private Pilot Practical Test Standard (FAA, 2002).

Navigation Error: Second Pass The graph in Figure 4 shows the mean navigational errors during the second pass through the circuit for all three groups: when pilots had all navigation resources taken away from them.

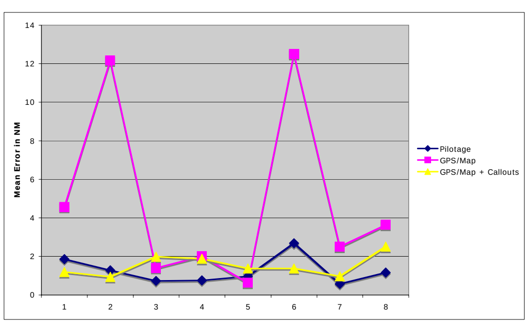

Figure 4. Navigational accuracy with no navigational resources available.

The data in Figure 4 show that the practice of choosing and pointing out geographical features resulted in a significant improvement in navigational performance for users of GPS and moving maps. While the mean navigational error for the GPS/Map group was 4.92 NM (7.92 NM), navigational error for the GPS/Map group that pointed out geographical features was 1.53 NM (1.42 NM).

Conclusion

The results of the first experiment clearly show that pilots believe that GPS and moving maps categorically enhance pilot navigational awareness, when in fact they do not. Pilots may consider navigational awareness to extend beyond what the pilot is aware of in the traditional sense. That is, pilots may have considered the information stored inside the computer to be part of their awareness.

The results of the second experiment suggest that the loss of navigational awareness may be related to pilots' understanding of their own role in the cockpit when GPS and moving maps are used. It may be that pilots have a natural tendency to assume a passive role when these systems are used. The simple intervention employed in Experiment 2 suggests that a more cooperative relationship between pilot and advanced systems might deliver more of the promised benefits of advanced systems.

A more complete description of Experiment 1 can be found in Casner (2005). A more complete description of Experiment 2 can be found in Casner (2006).

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