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13. ABSTRACT (Maximum 200 words)
This study was designed to explore GPS/LORAN receiver programming performance under simulated flight conditions. The programming task consisted of entering, editing, and verifying a four-waypoint flight plan. The task demands were manipulated by varying flight turbulence and the time interval between test sessions. Flight performance data indicated that subjects were well trained on the flight task; significant effects of turbulence and test interval were not found. Programming performance was very good and critical errors occurred on only 13% of the test trials. Examination of the conditions surrounding each error indicated that specific display design and system logic attributes contributed to the errors. In addition, examination of error recovery methods showed that non-intuitive menu structures complicated and confused the recovery process. Pilots rarely recalled "doing anything wrong" when errors occurred, suggesting that the receiver interface design was opaque and did not provide a good understanding of system function. Recommendations for GPS/LORAN receiver controls, functions, menu structure and logic, error recognition and recovery, and general usability are discussed.

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PREFACE

This report describes an experiment which examined pilot GPS/LORAN programming performance as a function of simulated flight turbulence and test interval. Five pilots, qualified for instrument flight, completed the study. Examination of programming performance suggested that receiver logic and display characteristics contributed to specific programming errors. Receiver design recommendations, based on programming performance, pilot opinion, and experimenter observation, were made.

This study is the first in a series of efforts at the Volpe National Transportation Systems Center (VNTSC) to develop human performance-based design guidelines for GPS/LORAN receivers. This research was completed under the direction of M. Stephen Huntley, Jr., Program Manager of the VNTSC Cockpit Human Factors Program, and Donald Eldredge, Program Manager of the Transportation Systems Group, Battelle Memorial Institute. The research and report preparation were the responsibilities of Edwin F. Madigan, Jr. and Vicki M. Shearer, Battelle Memorial Institute.

This work was funded by the Human Performance Program of the FAA's Research and Development Service as part of its cockpit human factors research activities.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in.)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

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1 square yard (sq yd, yd ²)	=	0.8 square meter (m ²)
1 square mile (sq mi, mi ²)	=	2.6 square kilometers (km ²)
1 acre	=	0.4 hectares (he) = 4,000 square meters (m ²)

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1 pound (lb)	=	.45 kilogram (kg)
1 short ton	=	2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft ³)	=	0.03 cubic meter (m ³)
1 cubic yard (cu yd, yd ³)	=	0.76 cubic meter (m ³)

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METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm ²)	=	0.16 square inch (sq in, in ²)
1 square meter (m ²)	=	1.2 square yards (sq yd, yd ²)
1 square kilometer (km ²)	=	0.4 square mile (sq mi, mi ²)
1 hectare (he)	=	10,000 square meters (m ²) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg) = 1.1 short tons

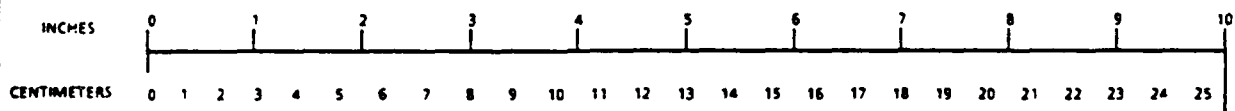
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1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m ³)	=	36 cubic feet (cu ft, ft ³)
1 cubic meter (m ³)	=	1.3 cubic yards (cu yd, yd ³)

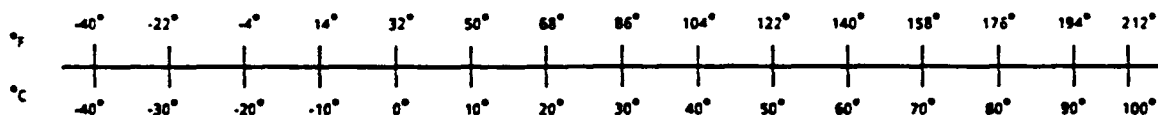
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EXECUTIVE SUMMARY

Global Positioning System (GPS) technology is becoming more widely used and may eventually replace existing precision navigation systems (e.g., Instrument Landing System). To a large degree, current GPS receiver designs are based on previous Long-Range Navigation (LORAN) receiver designs. A problem with this approach is that current LORAN receiver designs have been shown to be lacking with respect to usability.

Issues of system logic, receiver complexity, and display design were among the critical human factors issues expressed by pilots as lacking on most GPS/LORAN receiver designs (Adams, Adams, Huntley, & Eldredge, 1992). These issues, to name a few, combine to determine the usability of a system. Typical concerns were: non-intuitive and overly complex menu structures, multifunction knobs/keys that contribute to confusion and forgetting, and a lack of necessary display prompting.

In order to provide design recommendations for future receivers, current receivers must be evaluated and design inadequacies must be identified. The purpose of this study was to determine the conditions that contribute to pilot GPS/LORAN programming errors and make design recommendations based on pilot performance and subjective reports.

Five pilots rated for instrument flight (IFR) participated as subjects. Subjects were trained to fly a simulator, program and edit a flight plan on a common GPS/LORAN receiver, and program and edit the receiver while flying the simulator. Flight turbulence was manipulated according to three levels, and the time between the first and second test day was varied (7 or 14 days). Flight performance (crosstrack error and altitude deviation), programming performance (programming time, programming errors, and recovery time), and subjective reports (pilot questionnaires, error checklists, and general comments) were collected and analyzed.

Flight performance data indicated that subjects were well trained on the flight simulation task and minimal effects of turbulence and test interval were found across test session. Pilot programming performance was very good and major errors were only found on 13% of all flight/program trials. Although few errors were committed, examination of the conditions surrounding each error indicated that display design and system logic attributes were contributory factors. In addition, examination of error recovery methods showed that non-intuitive menu structures complicated and confused the recovery processes.

Pilot comments were sparsely related to the specific errors that occurred and pilots rarely recalled "doing anything wrong" after an error was made. This suggests that current GPS/LORAN designs are opaque and do not provide a good understanding of system function to the pilot. Some pilots developed strategies to cope with the demands of both the flight and programming tasks, suggesting that pilots were attempting to gain an understanding of the GPS/LORAN receiver system function.

Recommendations are made with respect to receiver controls, functions, menu structure, display design, and general usability. Future research issues related to GPS/LORAN use within the National Airspace System and the effects of menu structure, error recognition, and error recovery are discussed.

1. INTRODUCTION

Global Positioning System (GPS) technology has the potential to enhance pilot performance by providing accurate and timely navigation information. The need for this information is great for general aviation pilots. As GPS becomes more affordable it is predicted to expand and may replace present navigation systems (e.g., Long-Range Navigation systems, Instrument Landing Systems). Because GPS is becoming more widely used, it is important to understand how GPS receivers affect pilot performance and flight safety.

Preliminary studies indicate that current GPS/LORAN receivers may not fully support pilot performance. A large number of issues were identified in a recent survey of GPS/LORAN users that focus on system usability as the underlying problem area (Adams et al., 1992). System logic, complexity, and display design were among the critical human factors concerns that affect usability. Examples of system logic difficulties include pilots getting lost within the menu structure associated with system modes and functions. The organization of information pages were found to be non-intuitive and cumbersome. Pilots reported that searching behaviors and pure memorization were often required in order to find and utilize receiver functions. These behaviors can be particularly problematic during in-flight operations because they contribute to "head-down" time and hence, have the potential to compromise flight safety.

The high degree of system complexity related to controls and hardware issues also contribute to degraded usability. Due to the high demand for panel space, system designers are forced to employ the use of multifunction knobs and keys. The problem with this approach is that often times, one control manipulation (e.g., a key press) will have many different and unrelated functions depending upon the current mode of the receiver. As a result, it is difficult for pilots to gain a good understanding about the relationships between control manipulation and system function. This can be further complicated by the fact that most general aviation pilots do not maintain regular flight schedules and therefore are prone to forgetting over short periods of time (Adams et al., 1992).

An additional concern is the issue of display design. A lack of good system logic and structure combined with high complexity creates situations in which pilots are unsure about how to access information or initiate functions. Adams et al. (1992) report that current receivers are lacking with respect to necessary display prompts. That is, systems do not provide information about the required steps that are needed to accomplish a procedure or function. Furthermore, these receivers often do not provide pilots with useful error messages. This increases the likelihood that pilots may not recognize errors, or may become lost during error recovery procedures once an error has been identified.

Based on pilot input, it is clear that current GPS/LORAN receiver designs do not fully support pilot performance. Given that these systems may become critical for precision navigation tasks, future receiver designs must consider the above human factors concerns.

Perhaps the most critical issue is that current receiver designs have the potential to degrade performance, particularly in single-pilot aircraft.

1.1 PRESENT RESEARCH ISSUES

Field studies have indicated that current GPS/LORAN receiver designs are lacking. If pilots are going to fully benefit from new and existing technology, the issues of usability and receiver design must be investigated in the laboratory. The difficulties associated with current designs must be systematically examined in order to make design recommendations for the next generation GPS/LORAN receiver.

This study was designed to achieve two goals. One goal was to examine the issues associated with receiver usability and to make design recommendations based on programming performance and subjective reports. A second goal was to develop a methodology for future pilot-GPS research.

A variation of the secondary task method (see Wickens, 1984) was used to examine GPS/LORAN programming performance. Subjects were required to time-share flying a simulator with programming a GPS/LORAN receiver. Flying the simulator served as the primary or loading task, and programming the receiver served as the secondary task. The turbulence associated with the flight simulation and the time interval between test sessions were varied. Thus, programming performance should vary as a function of turbulence and test interval.

Turbulence (random roll and pitch inputs) was chosen for two reasons. First, it provides a controlled method to vary the attentional demands associated with the flight task. Second, the addition of turbulence provides a level of difficulty that is analogous to real-world conditions. Although the turbulence manipulation is not completely realistic, it does require subjects to monitor their flight instruments as they would be expected to in actual turbulence conditions. Attention theories (e.g., Kahneman, 1974; Wickens, 1984) postulate that: 1) Attention is a limited commodity, 2) tasks compete for attention, and 3) degraded performance is caused by a lack of sufficient attention to perform a task. Therefore, it was predicted that GPS/LORAN programming performance should degrade as turbulence is increased. As the flight task becomes more difficult, less attention would be available to program the receiver and performance should degrade.

Test interval was chosen to mimic the time delay that typically occurs between flights among general aviation pilots. All subjects received one training session and two test sessions. The effects of test interval were examined by varying the amount of time between the first and second data collection sessions. One group of subjects returned to complete the second test session after a 7-day interval; a second group returned after 14 days. It was predicted that programming performance for the 14-day group would be worse than the 7-day group because of the potential for increased forgetting.

1.2 OBJECTIVES

To address the issues outlined above, this study was designed to investigate pilot GPS/LORAN programming performance as a function of turbulence and test interval. The objectives of the study were to:

1. Examine GPS/LORAN programming performance during simulated flight and identify the design attributes that contribute to poor performance.
2. Identify which aspects of receiver programming are forgotten over time.
3. Examine the effects of increased turbulence on programming performance.
4. Provide potential solutions to the interface design problems discovered in Objectives 1, 2, and 3.
5. Refine the experimental, data collection, and measurement techniques for future research on GPS/LORAN receiver design.

2. METHOD

2.1 SUBJECTS

Five pilots licensed and current for instrument flight (IFR) participated as subjects. All subjects had a minimum visual acuity of 20/20 (normal/corrected) as determined by a Graham-Field eye test chart (model 2867-1264). Two subjects were employees of the Volpe National Transportation Systems Center (VNTSC) and were given an account number to charge their time. Three subjects unaffiliated with VNTSC were each paid \$100.00 for participation.

2.2 APPARATUS

The laboratory was equipped with two banks of variable level fluorescent lights. Visual acuity testing was performed at an ambient illumination of 128 foot candles (approximately 1377 lux). The experimental trials were performed at an ambient illumination of 5.6 footcandles (approximately 60 lux). Luminance was measured at the subject's approximate head position using a Sylvania GTE light meter (model DS-2050). The major equipment groups were: flight simulator and controls, GPS/LORAN receiver, and audio/visual equipment; each are described below. Figure 1 illustrates the layout of the apparatus.

2.2.1 FLIGHT SIMULATOR

The flight simulation and display instruments were generated using a 486 MHz, IBM compatible micro-computer with Instrument Flight Trainer software (IFT-PRO V5.1). The flight dynamics and instrument display were configured to mimic a Cessna 172. The flight instrumentation was displayed on a 16" NANA0 9080i VGA monitor (model # MA 1660) as shown in Figure 2. The flight display subtended a horizontal visual angle of 30.4° and a vertical visual angle of 24.2° (assuming a viewing distance of 20.0 inches).

The primary flight instrumentation included: a turn/slip indicator, airspeed indicator, attitude indicator, directional gyroscope, altimeter, vertical speed indicator, and a very-high-frequency omni-directional range indicator (with course deviation needle). The outside view was always gray to ensure that pilots were using only flight instruments to receive attitude and direction information. A description of all flight instruments is provided in Appendix A.

Flight control was made using a Novel Twist (model # NT-360) flight trainer that consisted of a control panel, yoke, and a rudder pedal assembly. Subjects were required to control flight using only the yoke and rudder pedals. The control yoke provided control of pitch and roll. The range of pitch control was 6.4" of fore/aft travel with a control resolution of 16 positions per inch. Roll control ranged from +/- 90° of lateral rotation from center with

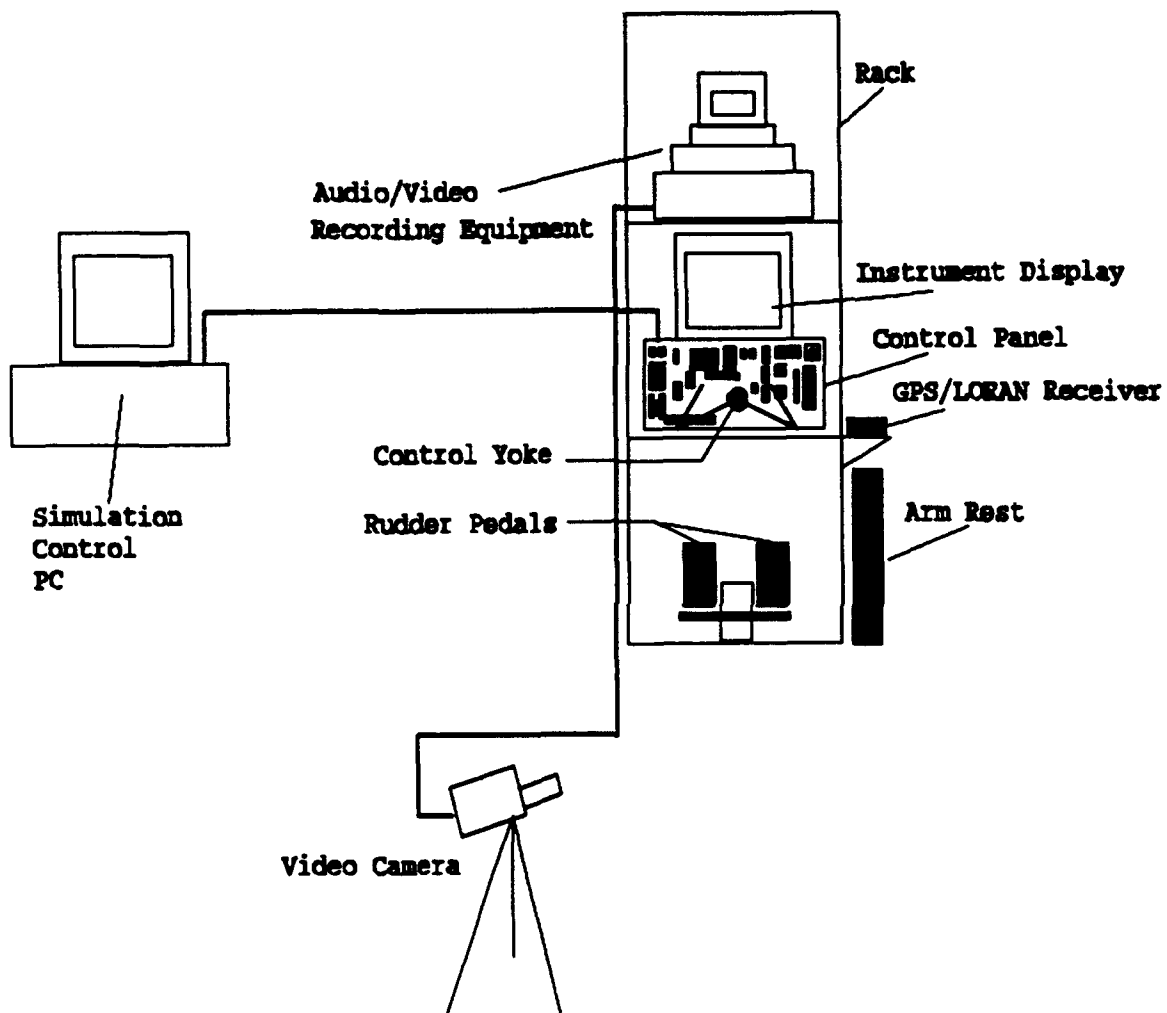


FIGURE 1. EXPERIMENTAL APPARATUS

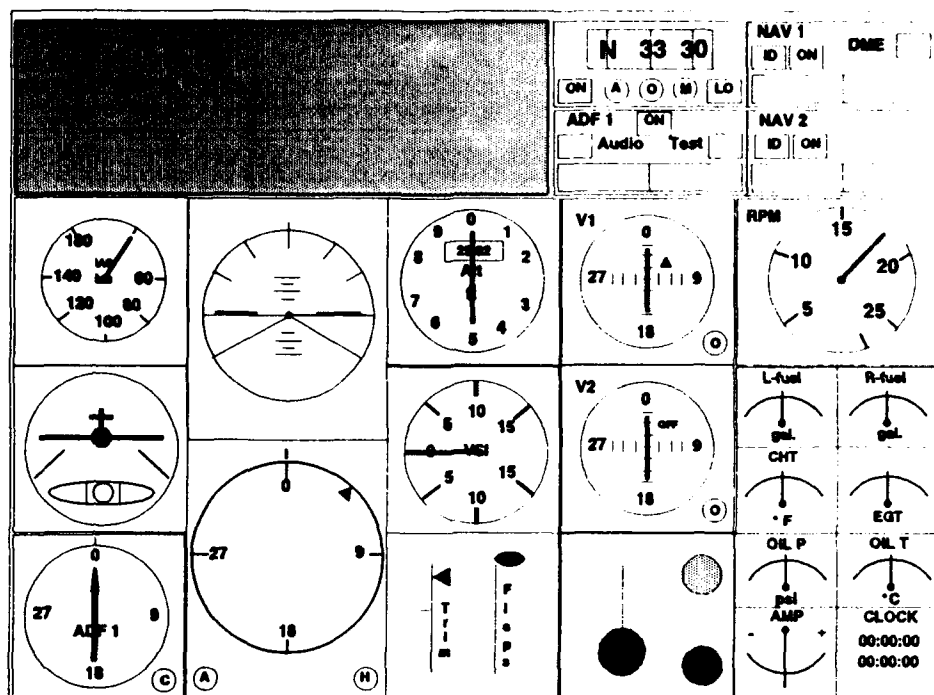


FIGURE 2. FLIGHT INSTRUMENTS DISPLAY

a control resolution of 32 positions per 90° of rotation. Yaw was controlled by rudder pedals that had a range from ± 3.25 " and a resolution of 6 positions per inch.

Under certain conditions, subjects were required to use the "pause" key on the NT-360 panel to terminate a trial. Subjects were not allowed to adjust the flight attitude by using the elevator trim or throttle controls. An exhaustive description of the NT-360 control panel can be found in Brasington (1990).

2.2.2 GPS/LORAN RECEIVER

A common GPS/LORAN receiver was mounted approximately 33.5 inches above ground level and 17.5 inches to the right of the NT-360 control yoke. This placement was chosen to mimic typical locations found in general aviation aircraft. An arm rest (28.0 " high x 6.5 " wide) was provided to reduce arm fatigue.

The physical dimensions of the receiver were approximately 6.25 by 2.0 inches in width and height, respectively. Figure 3 illustrates the receiver face plate. The unit was equipped with

two amber colored, light emitting diode (LED) displays. Each display measured approximately 0.375 inches (height) by 3.0 inches (width). The secondary display subtended a horizontal visual angle of 0.81° and a vertical visual angle of 6.46° (assuming a viewing distance of 26.5 inches). Each display was controlled with two concentric control knobs and three keys. The left-hand set of knobs and keys controlled the primary display and the right-hand set controlled the secondary display.

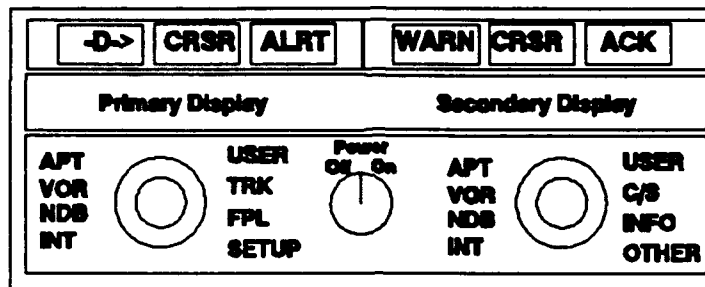


FIGURE 3. GPS/LORAN RECEIVER FACEPLATE

In general, the outer knob is used to select a specific function and the inner knob is used to control data associated with the selected function. Five waypoint categories were available on each side of the receiver: APT (Airport), VOR (Very High Frequency Omni-Directional Range transmitter), NDB (Nondirectional Radio Beacon), INT (Intersections), and USER (User defined waypoints).

The cursor (CRSR) key operates as an on/off toggle to assist with data entry. Pressing CRSR once begins the data entry process, pressing CRSR again terminates data entry. During waypoint entry, the inner knob is used to scroll characters and the outer knob is used to control cursor position. Users may also scroll entire waypoint identifiers using only the inner knob once a category is selected. The acknowledge (ACK) key has many functions. For the purpose of this study, it was primarily used to begin flight plan entry, confirm waypoint entry and editing functions, and to advance positions while entering a flight plan. The ACK key prompts users by flashing on/off during the flight plan entry process.

2.2.3 AUDIO/VISUAL RECORDING EQUIPMENT

A Panasonic Digital 5000 System video camera and a Panasonic VHS video cassette recorder (model GX4 AG-1950) were used to record programming behavior. Audio information was recorded using a Realistic microphone (model 33-1090 PZM), an Optimus 10-band equalizer, and a Realistic stereo-mixing console.

2.3 EXPERIMENTAL TASKS

Subjects performed three types of tasks: the flight task, the GPS/LORAN programming task, and the combined flight/program task. A brief description of each of these tasks follows. The specific order and number of trials is described later (see the PROCEDURE section).

2.3.1 FLIGHT TASK

The goal of the flight task was to maintain aircraft altitude and heading on a preset, straight and level flight path. The course heading was set to 292 degrees and subjects were not explicitly given this information. Subjects were instructed to keep the course deviation needle centered on the number one VOR while maintaining altitude to within +/- 100 feet of the preset 5000 foot value. Airspeed was preset at 100 knots and varied only with aircraft attitude changes; subjects were not allowed to manipulate the throttle control.

The turbulence associated with each flight trial was manipulated by varying the turbulence parameter of the flight simulation software. Three turbulence levels (low, medium, and high) were chosen and verified by subject matter experts as providing distinct levels of flight difficulty. The turbulence level assigned to a specific trial did not change within a trial. Each single task flight trial lasted four minutes and was terminated by the experimenter. Crosstrack error and altitude deviation measures were displayed on the subjects monitor at the end of each trial to provide feedback and enhance subject motivation.

2.3.2 GPS/LORAN RECEIVER PROGRAMMING TASK

The GPS/LORAN receiver was programmed to run in simulation mode and did not provide dynamic position information. The programming task consisted of three parts: 1) Program a four-waypoint flight plan, 2) edit the flight plan, and 3) check the accuracy of the flight plan. Figure 4 depicts the stages of the programming task and Appendix B shows a sample flight plan.

Each flight plan consisted of four-waypoint identifier names and their respective waypoint categories (e.g., VOR, APT, USER, INT, or NDB). The flight plans were developed using sectional charts and were designed to include different categories throughout each position in the flight plan. An unique flight plan was developed for each receiver programming trial. Each flight plan was entered into the GPS/LORAN receiver prior to the experiment to ensure that all waypoints were contained in the receiver database.

Figure 4 illustrates the basic steps required to enter a flight plan. Waypoint entry could be achieved by using either the scrolling or cursor entry methods (see Appendix C for waypoint entry procedures). Note that steps 2-4 are repeated until the specific number of waypoints are entered into the flight plan. At step 5, subjects are required to exit and enter the flight

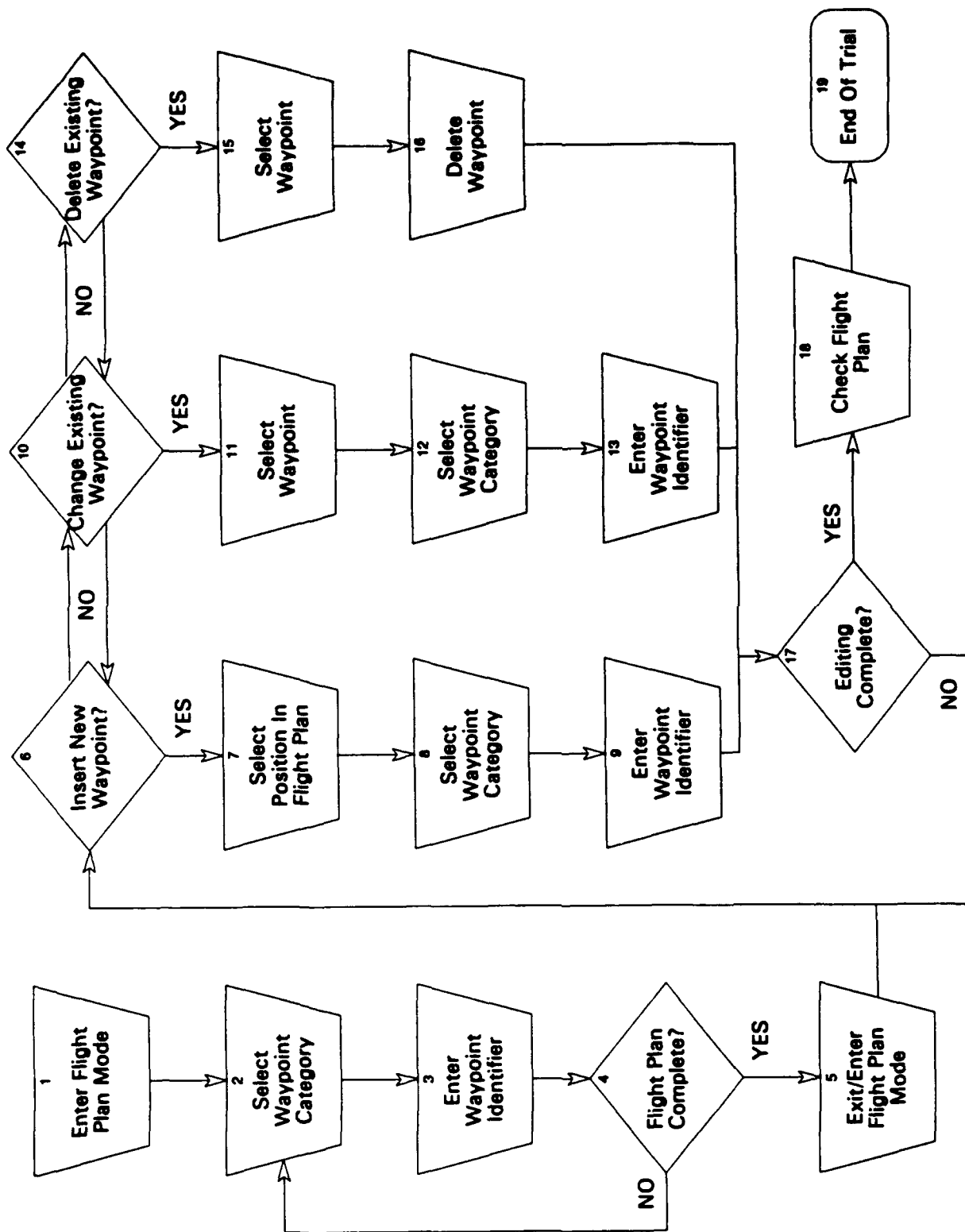


FIGURE 4. GPS/LORAN PROGRAMMING TASK FLOW CHART

plan mode by turning the large, primary control knob one detent and back. At this point, the secondary display shows the flight plan leg (e.g., 1st leg, 2nd leg) and the primary display shows the waypoints of that leg (e.g., SXD n to EEN v).

Next, the editing sequences (at step 6, 10, or 14) were performed and always involved inserting, deleting, and changing waypoints. The order of these functions was counterbalanced across trial. When the editing portion of the task was completed, subjects were asked to check the accuracy (step 18) of the flight plan by consulting the flight plan printed on the reverse side. Although the single task programming trials were self-paced, subjects were encouraged to program as quickly as possible but were required to maintain 100% accuracy. Short-cuts to obtain a correct, final flight plan were discouraged. That is, subjects were explicitly told to follow the exact sequence as printed on the flight plan.

2.3.3 FLIGHT/PROGRAM TASK

The flying and programming tasks were combined in these trials. Subjects were asked to maintain the flight in the same manner as during the single task flight trials in addition to programming, editing, and checking a flight plan. Verbal instructions stressed that primary emphasis must be given to the flight portion of the task. The initial flight parameters were exactly the same as those used during flight training. Subjects were instructed to maintain their altitude at ± 100 ft, and use the CDI to maintain their course as accurately as possible.

Prior to the start of each trial, subjects were given a flight plan, face-down on the kneeboard. Subjects were allowed to commence programming after thirty seconds of the trial had elapsed (signaled by the experimenter). This 30 second period allowed subjects the opportunity to establish a relatively stable flight profile.

Subjects were responsible for terminating the flight/program trials, after verifying the accuracy of the flight plan, by pressing the pre-designated "pause" button on the NT-360 control panel. The trial duration and flight performance measures were then recorded by the PC and performance feedback was displayed on the subject's monitor in place of the flight instrument display.

2.4 EXPERIMENTAL DESIGN

A mixed experimental design was chosen to examine the effects of turbulence and test interval on GPS/LORAN programming performance (see Table 1). The within-subjects independent variables were task (flight only or flight/program) and turbulence (low, medium, or high). The time interval between the first and second test days (7 or 14 days) was initially chosen as the between-subjects independent variable. Due to time constraints, three subjects completed the 14-day test interval condition and two subjects completed the 7-day condition. As a result, the between-subjects variable of test interval was collapsed to represent a "global"

factor of test day. That is, the data recorded on the 7th or 14th day were uniformly treated as the second test day data.

TABLE 1. EXPERIMENTAL DESIGN

Training Session	Test Day 1	Test Day 2
Fly or Program	Fly or Program (warm-up)	Fly Only (warm-up)
Program or Fly	Program or Fly (warm-up)	Fly/Program
BREAK	BREAK	Fly/Program
Fly/Program	Fly/Program	BREAK
Fly or Program	Fly/Program	Fly/Program
BREAK	BREAK	Fly/Program
Program or Fly	Fly/Program	
Fly/Program	Fly/Program	

2.5 PROCEDURE

All subjects performed one training session and two test sessions. The first test session for all subjects was completed one day following training. Subjects were randomly assigned to either test interval condition (7 or 14 days) for the second test session. Detailed procedures and instructions are shown in Appendix D; each session is described below.

2.5.1 TRAINING SESSION

After completing the visual acuity test, each subject read and signed an informed consent form that summarized the purpose and general procedures of the experiment (see Appendix E). Next, subjects completed the pilot experience questionnaire (see Appendix F). This questionnaire was designed to obtain demographic data, flight experience, and previous GPS/LORAN experience. When applicable, subjects were asked to rate the performance characteristics associated with previously operated GPS/LORAN receivers and provide general design recommendations.

Subjects were randomly assigned to a counterbalanced task condition sequence. The order of single task conditions and the turbulence levels for the dual task conditions were counterbalanced. Subjects were familiarized with either the programming task or the flight task, depending upon the task order sequence they were assigned. Two subjects performed a block (three trials) of programming trials first, followed by a block of flight trials. Three subjects performed a block of flight trials first, followed by a block of programming trials. For the single task flight and dual task flight/program trials each turbulence level was performed once in a block and always progressed from low to high to facilitate learning. After single task practice, subjects performed a block of flight/program trials.

This sequence was repeated in the same order for the second half of the Training Session. Breaks lasting approximately 10 minutes were provided after every second block of trials. Overall, subjects performed 18 trials during the Training Session (6 program trials, 6 flight only trials, and 6 flight/program trials; 2 repetitions at each turbulence level).

2.5.2 TEST DAY 1

Subjects performed a block of programming trials followed by a block of flight trials, or the reverse, to serve as warm-up. The task order was identical to that of the training session for a given subject. Questions concerning the GPS/LORAN receiver could be answered only during warm-up trials, after this period subjects were forced to remedy problems on their own.

Following the warm-up trials, subjects performed four blocks of flight/program trials consisting of three trials per block. Each turbulence level was performed once per block in a counter-balanced order. If a programming error occurred, subjects were questioned about the nature of the error immediately following the trial. A checklist of possible responses was used for prompting (see Appendix D) and subjects were given the opportunity to elaborate on the reasons behind the errors. Two 10 minute breaks were provided throughout the session. Overall, subjects performed 18 trials for Test Day 1 (3 programming trials, 3 flight trials, and 12 flight/programming trials; 4 repetitions at each turbulence level).

2.5.3 TEST DAY 2

Subjects returned in either 7 or 14 days, depending on the group they were assigned to, and performed two single-task flight trials for warm-up. To keep the overall number of trials low without compromising warm-up, both the low and high turbulence conditions were performed. The first trial was always a low turbulence trial and the second was always a high turbulence trial. No receiver programming warm-up was given and subjects were not provided any assistance from the experimenter concerning the programming task. Following the flight task warm-up trials, subjects performed four flight/program blocks in the same order as during Test Day 1.

Subjects were questioned about any programming errors using the same checklist as in Test Day 1, and a 10 minute break was provided midway through the session. Overall, subjects performed 14 trials for Test Day 2 (2 flight trials, and 12 flight/programming trials; 4 repetitions at each turbulence level). When all trials were completed, subjects were asked to complete a post-experiment questionnaire (see Appendix G). The purpose of this questionnaire was to allow subjects to elaborate on any positive or negative aspects of the GPS/LORAN receiver. Subjects were also asked to list any desired navigation information that a GPS/LORAN receiver should display and to provide design recommendations concerning the knobs/keys, labeling, displays, and procedures.

2.6 PERFORMANCE MEASURES

2.6.1 FLIGHT PERFORMANCE

The difference between the aircraft's position and the centerline of the desired course (i.e., crosstrack error) was measured in feet. Crosstrack error was sampled once per second and the root mean square (RXTK) for each trial was computed. The difference between the aircraft's altitude and the desired altitude (i.e., altitude deviation) was measured in feet. Altitude was sampled once per second and the root mean square (RALD) was computed for each trial.

2.6.2 PROGRAMMING PERFORMANCE

The video recordings were examined to provide information about both error and error-free programming performance. To determine the programming time associated with each part of the programming task, the total time-on-task was divided into three segments. The time to enter a flight plan was defined as the beginning of each flight/program trial (i.e., the 30 second mark signaled by the experimenter) up to the final correct waypoint entry. This signalled the beginning time for the editing task which ended when the final waypoint was successfully edited. The remaining time up to the end of the trial was categorized as accuracy checking time. These times were summed to provide a measure of total programming time for the error-free trials.

A second goal was to determine the conditions under which errors occurred and to examine error recovery. An error was defined as a control manipulation that interrupted the progress of the programming task and required additional control manipulations in order to return to an error-free state. Error time was defined as the point at which an incorrect control manipulation was initiated until recovery from the error was achieved. The steps required to recover were analyzed to provide information about the subjects' knowledge of system logic and to evaluate the design attributes of the receiver.

2.6.3 QUESTIONNAIRES

The pilot experience questionnaire was designed to gather demographic and qualitative data, and to solicit design recommendations based on previous GPS/LORAN experience (see Appendix F). All closed-end questions were rated on a 7-point Likert-type scale, where: 1 = "very easy," 2 = "easy," 3 = "somewhat easy," 4 = "neutral," 5 = "somewhat difficult," 6 = "difficult," and 7 = "very difficult."

The post-experiment questionnaire was designed to gather the negative and positive aspects (if any) associated with the programming task (see Appendix G). Subjects were also asked to provide specific design recommendations based on experience gained in the present study. In addition, comments related to programming errors and general comments about the experiment were collected and analyzed.

3. RESULTS

The results described below are grouped according to six sections. Pilot flight and GPS/LORAN experience are reported based on the responses provided on the pilot experience questionnaire. Flight performance measures recorded for the flight only and flight/program conditions are described in the next section. The programming performance measured in the flight/program trials of the first and second test days are divided into an error-free performance section and a programming errors section. It is important to note that because only five subjects completed the study, limited significance testing was performed on the performance data. Mean and median scores are reported to examine trends in the data. Lastly, subjective data are reported in the post-questionnaire and general comments sections.

3.1 PILOT FLIGHT AND GPS/LORAN EXPERIENCE

Subjects' ages ranged from 29 to 62 years, with a median age of 50 years. Total flight time (actual and simulated flight) ranged from 300 to 21,000 hours, with a median of 1,100 hours. Total IFR time (actual and simulated flight) ranged from 60 to 700 hours, with a median of 218 hours. All subjects reported having general aviation experience, one subject reported having both Part 121 and Part 135 experience. The types of aircraft that subjects were currently experienced with were: Cessna 172/210, Beechcraft 58/76/Duchess, Piper 28, and an Aerostar 700.

Three of five subjects had prior experience with either the ARNAV R50i, ARNAV FMS, and the KLN 88 type LORAN receivers. The ratings associated with the usability and the design recommendations for each receiver are provided below.

The estimated time in use during flight for the ARNAV FMS was 10%. The readability of the display panel, flight plan creation, flight plan editing, controls operation, and overall usability were each rated as "easy." Error recovery was rated as "very easy." Waypoint entry was reported as causing a brief distraction from primary flight duties and no design changes were recommended for this receiver.

The readability and error recovery of the ARNAV R50i were each rated as "very easy." Flight plan creation, editing, and overall usability were each rated as "easy", and controls operation was rated as "somewhat easy." This receiver was estimated as being used 100% of the time. Operation of this receiver was rated as non-distracting from primary flight duties, however, the "Direct-To-Waypoint" procedure was rated as hard to remember.

The KLN 88 was estimated as being used 90% of the time. The overall usability and display readability were each rated as "very easy." Flight plan creation and editing were each rated as "somewhat difficult", and error recovery and controls operation were each rated as "neutral." This receiver was rated as non-distracting from primary flight duties and the only

design recommendation was for better documentation. It was suggested that flow chart presentation may simplify the procedures documentation.

3.2 FLIGHT PERFORMANCE

The root mean square crosstrack error (RXTK) and root mean square altitude deviation (RADV) scores obtained for each trial were averaged across condition (Task x Turbulence x Session). The RXTK data are listed in Table 2 and illustrated in Figure 5. Crosstrack performance was best for all single flight task conditions. Performance improved for the low and high turbulence conditions across session and was essentially equal during the warm-up trials of the second test day. Crosstrack error while programming was more variable during the training session but stabilized for the low and medium turbulence conditions during the first and second test days. Crosstrack error increased (non-significantly) on Test Day 2 for the high turbulence condition.

TABLE 2. ROOT MEAN SQUARE CROSSTRACK ERROR
BY TASK, TURBULENCE, AND SESSION

Task	Turbulence	Session		
		Training	Test Day 1	Test Day 2
Fly Only	Low	137.87 (62.46)	73.90 (19.39)	63.94 (7.93)
Fly Only	Medium	120.27 (58.61)	132.50 (71.48)	N/A
Fly Only	High	103.41 (50.06)	106.56 (44.99)	60.88 (0.67)
Fly and Program	Low	347.07 (222.31)	260.95 (219.76)	240.78 (227.82)
Fly and Program	Medium	283.09 (216.35)	280.55 (199.20)	234.43 (136.10)
Fly and Program	High	443.19 (276.87)	253.94 (176.32)	293.17 (195.46)

Note: Standard deviations are given in parentheses. No warm-up trials were performed for the medium turbulence condition of the second test day.

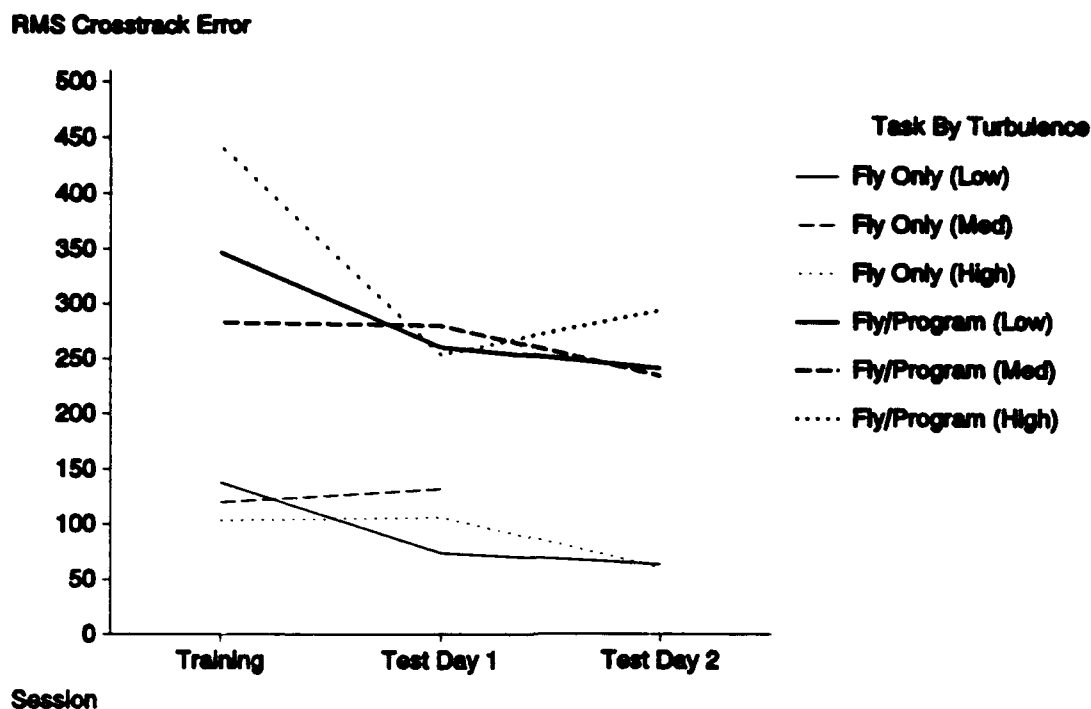


FIGURE 5. ROOT MEAN SQUARE CROSSTRACK ERROR AS A FUNCTION OF TASK, TURBULENCE, AND SESSION

The RADV data are listed in Table 3 and illustrated in Figure 6. The RADV scores show a trend similar to the RXTK scores in that performance under single task conditions was superior to all dual task conditions. Altitude deviation performance improved on the first test day for the low and medium turbulence conditions and remained stable for Test Day 2. Dual task performance improved across session for all levels of turbulence. Perhaps the most dramatic improvement was the decrease in altitude deviation across test days for the high turbulence condition. Post-hoc F-tests for simple effects revealed that performance was significantly better for the low ($F(1, 12) = 20.21, p < 0.01$) and medium ($F(1, 12) = 15.93, p < 0.01$) turbulence conditions of Test Day 1.

**TABLE 3. ROOT MEAN SQUARE ALTITUDE DEVIATION
BY TASK, TURBULENCE, AND SESSION**

Task	Turbulence	Session		
		Training	Test Day 1	Test Day 2
Fly Only	Low	22.79 (7.02)	12.80 (4.01)	14.84 (4.80)
Fly Only	Medium	22.28 (5.91)	14.14 (3.38)	N/A
Fly Only	High	18.87 (5.80)	17.12 (6.51)	19.80 (7.80)
Fly and Program	Low	37.28 (13.78)	32.20 (10.53)	32.99 (15.33)
Fly and Program	Medium	50.12 (34.92)	33.75 (11.33)	28.39 (12.52)
Fly and Program	High	47.67 (9.57)	46.04 (48.32)	33.40 (16.29)

Note: Standard deviations are given in parentheses. No warm-up trials were performed for the medium turbulence condition of the second test day.

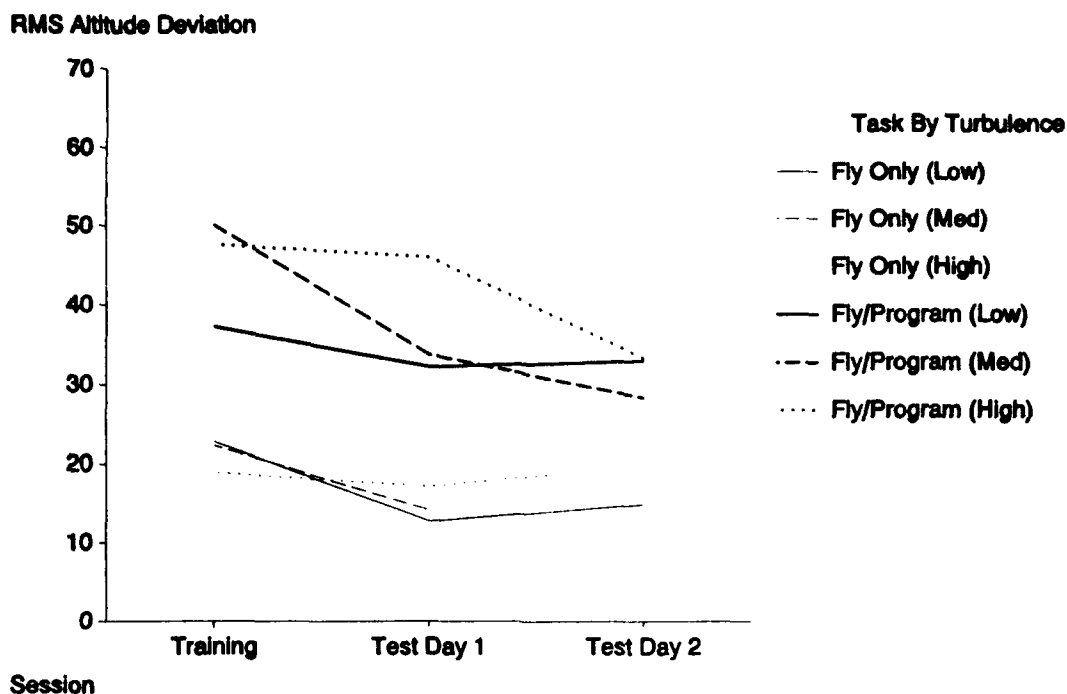


FIGURE 6. ROOT MEAN SQUARE ALTITUDE DEVIATION AS A FUNCTION OF TASK, TURBULENCE, AND SESSION

3.3 ERROR-FREE GPS/LORAN PROGRAMMING PERFORMANCE

Programming performance from the flight/program trials of Test Days 1 and 2 were examined to determine the effects of turbulence and test interval. The training and warm-up trials were omitted from all programming performance analyses. Subjects performed 104 of 120 possible trials without an error for an overall accuracy rating of 87%.

The mean programming times according to test day (one or two), programming task phase (entry, edit, accuracy check, and total time), and turbulence level (low, medium, and high) are provided in Table 4. Figure 7 shows the mean time required to complete all phases of the programming task as a function of test day and turbulence. On the average, programming time increased linearly across the low ($\bar{M} = 304.23$), medium ($\bar{M} = 361.65$), and high ($\bar{M} = 374.33$) turbulence levels. The effect of test day was nearly uniform for each level of turbulence with the exception of the high turbulence condition of the second test day. Subjects required slightly more time (non-significant) at the highest turbulence level of the second test day ($\bar{M} = 384.5$) as compared with the first test day ($\bar{M} = 364.16$).

**TABLE 4. PROGRAMMING TIME FOR ERROR-FREE TRIALS
BY TEST DAY, TASK PHASE, AND TURBULENCE**

Test Day	Task Phase	Turbulence		
		Low	Medium	High
1	Entry	123.44 (35.21)	171.33 (62.02)	164.53 (65.58)
1	Edit	153.50 (63.52)	163.93 (40.45)	167.00 (70.05)
1	Accuracy Check	29.72 (14.31)	27.27 (12.32)	32.63 (18.22)
1	Total Time	306.67 (99.25)	362.53 (98.60)	364.16 (112.03)
2	Entry	141.33 (60.22)	172.72 (70.09)	181.79 (65.32)
2	Edit	140.00 (56.21)	161.89 (97.65)	176.71 (75.79)
2	Accuracy Check	20.44 (12.28)	26.17 (14.82)	26.00 (18.25)
2	Total Time	301.78 (112.34)	360.78 (165.61)	384.50 (127.95)

Note. All times are given in seconds. Standard deviations are given in parentheses.

In general, no appreciable performance differences by task phase were found. Examination of Table 4 shows that both flight plan entry and editing times increased as turbulence increased. Higher turbulence levels required more time to complete the task. In addition, Table 4 shows that subjects required less time to complete the accuracy checking phase on the second test day.

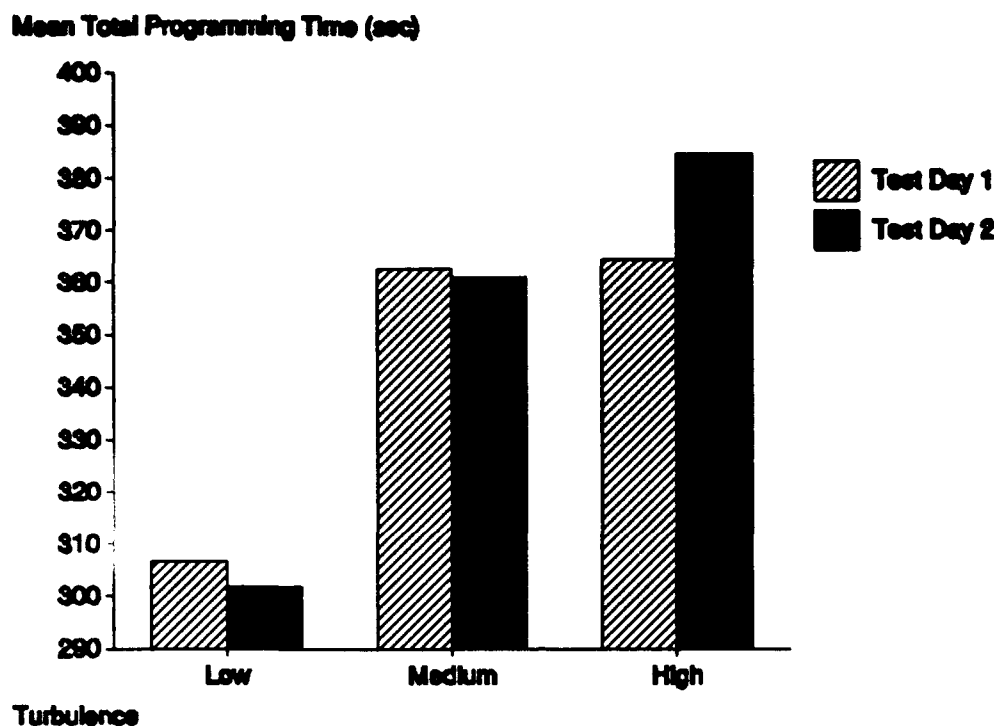


FIGURE 7. ERROR-FREE PROGRAMMING PERFORMANCE AS A FUNCTION OF TURBULENCE AND TEST INTERVAL

3.4 GPS/LORAN PROGRAMMING ERRORS

Errors occurred on 16 of 120 possible trials (13%). Table 5 lists the distribution of errors according to test day (one or two), task phase (flight plan entry or editing), and turbulence level (low, medium, or high). Generally, subjects committed more errors as turbulence increased. The fewest number of errors occurred at the lowest turbulence level ($n=3$) as compared to the medium ($n=6$) and high ($n=7$) turbulence levels. Seven errors were committed on the first test day and nine were committed on the second test day. Turbulence had a greater impact on performance of the second test day in which 6 out of 9 errors occurred at the highest turbulence level. Overall, more than twice as many errors occurred during flight plan entry ($n=11$) as compared to flight plan editing ($n=5$).

The errors were grouped according to the conditions surrounding each error. Four distinct categories were developed and each contained repeat occurrences. When possible, the recovery method and recovery time associated with each error was examined. Levels of

TABLE 5. PROGRAMMING ERROR FREQUENCY BY TEST DAY, TASK PHASE, AND TURBULENCE

Test Day	Task Phase	Turbulence			Total
		Low	Medium	High	
1	Entry	1	2	1	4
1	Edit	1	2	0	3
Total		2	4	1	7
2	Entry	1	2	4	7
2	Edit	0	0	2	2
Total		1	2	6	9
Total		3	6	7	16

confusion were recorded subjectively (e.g., low, medium, and high) to provide additional information about the error commission and recovery processes.

The Misspell Waypoint error did not involve a recovery process. In this case, the appropriate waypoint category was selected but the waypoint identifier was misspelled. The misspelled waypoint was contained in the database and therefore was accepted by the GPS/LORAN receiver. This error occurred twice and no recovery attempts were made during the flight plan entry phase of the task. This error was not noticed during the accuracy checking phase of the task because the waypoint was deleted during the editing phase as instructed. The correct waypoint identifier was "JIMIE" and the entered waypoint was "JIMMI."

Recoveries were made for the remaining three error categories. Only the Select Incorrect Waypoint Category error did not involve use of the acknowledge (ACK) key. The conditions surrounding each error, impact of the error, recovery method, mean recovery time, and frequency of occurrence are listed in Table 6. Each category is described in a separate section below and the mean recovery times for each category are illustrated in Figure 8.

TABLE 6. GPS/LORAN PROGRAMMING ERRORS CLASSIFICATION SCHEME

Error Type	Conditions Surrounding Error	Impact On Flight Plan	Recovery Method	Recovery Time/Frequency
Select Incorrect Waypoint Category	Wrong WPT Category; ACK Not Pressed	Increased Time-On-Task	Exit/Enter Flight Plan Mode	20.33 (3)
Default Waypoint Entry	ACK Pressed At Wrong Time	Default WPT(s) Entered Into Flight Plan	Random Controls Manipulation + Editing	104.20 (3)
Acknowledge Invalid Waypoint	Invalid WPT Identifier Entered + ACK Pressed	"Saved Position" Message	Random Controls Manipulation + Single ACK Press	158.30 (6)

Note. WPT = waypoint, ACK = acknowledge key, mean recovery times are given in seconds.

Mean Recovery Time (sec)

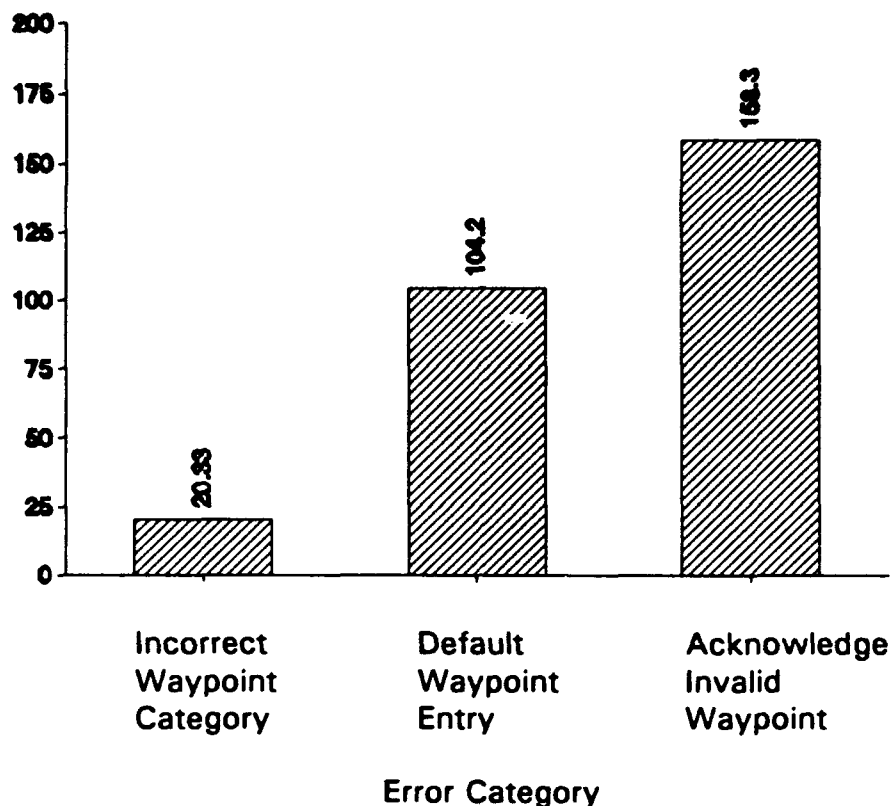


FIGURE 8. MEAN RECOVERY TIME BY ERROR CATEGORY

3.4.1 SELECT INCORRECT WAYPOINT CATEGORY ERROR

The Select Incorrect Waypoint Category error occurred when subjects selected an incorrect waypoint category (e.g., APT, VOR, NDB, INT, or USER), but did not attempt to enter a waypoint. Figure 9 illustrates the steps taken when this error occurred. This error occurred once at each turbulence level. The common method of recovery was to exit and re-enter the flight plan mode using the large primary knob. This action (see step 3 of Figure 9) essentially cleared any unacknowledged information and allowed programming/editing to continue without a complete restart. Because the error was recognized before waypoint entry was attempted, recovery was quick ($\bar{M} = 20.33$) and relatively easy.

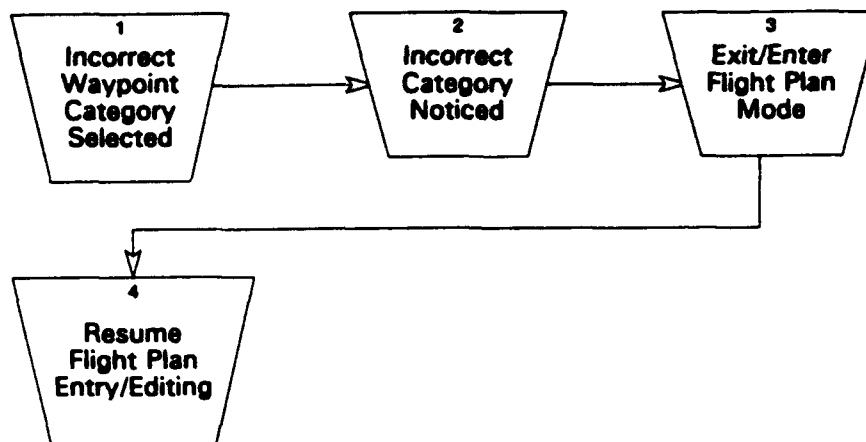


FIGURE 9. SELECT INCORRECT WAYPOINT CATEGORY ERROR

3.4.2 DEFAULT WAYPOINT ENTRY ERROR

When subjects pressed the acknowledge (ACK) key after selecting a category but prior to entering an identifier, a default waypoint was entered into the flight plan. This occurrence was classified as a Default Waypoint Entry error. Figure 10 illustrates the steps taken when this error occurred. This error occurred three times at the medium and twice at the high turbulence levels. All Default Waypoint Entry errors occurred during the flight plan entry phase.

One recovery method for the Default Waypoint Entry error was to edit the flight plan using the delete function and resume programming (see steps 1-5 and 10 of Figure 10). One subject recognized the error immediately, did not show any confusion, and corrected the error in 8 seconds using this recovery method.

For the remaining four occurrences, confusion ranged from medium to high and the mean recovery time was 128.25 seconds. In these cases, the recovery method included the execution of random knob turns and key presses until the editing functions were found (see steps 1-4 and 6-10 of Figure 10). On two occurrences, ACK was pressed multiple times and multiple default waypoints were added prior to recovery. The mean recovery time for all Default Waypoint Entry trials was 104.2 seconds.

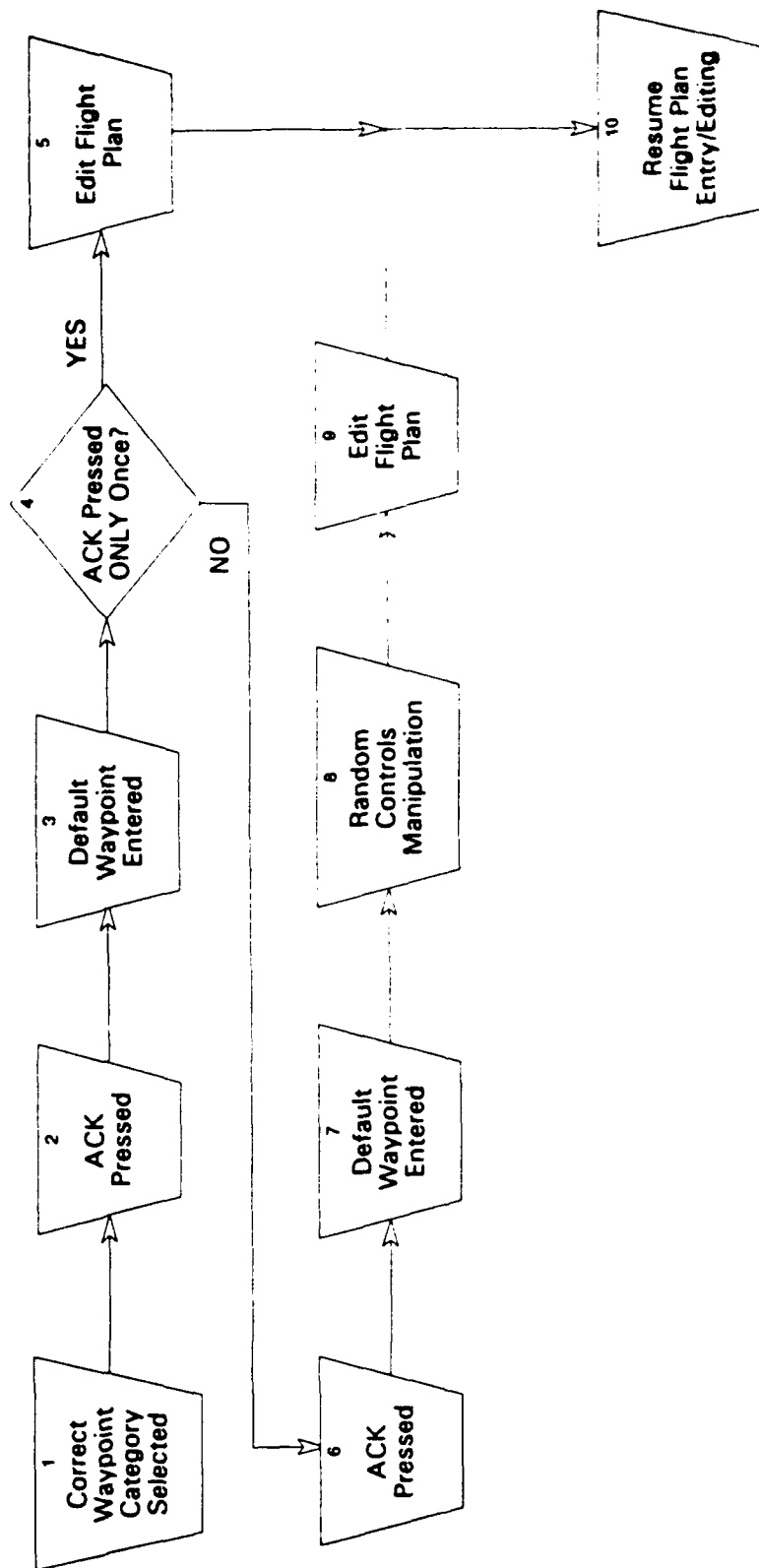


FIGURE 10. DEFAULT WAYPOINT ENTRY ERROR

3.4.3 ACKNOWLEDGE INVALID WAYPOINT ERROR

When subjects entered an incorrect category and/or identifier and pressed the ACK key, it was classified as an Acknowledge Invalid Waypoint error. This error is a combination of the Select Incorrect Waypoint Category and Default Waypoint Entry errors. These actions produced a "Saved Position" message on the secondary display and the ACK key became steadily illuminated. Figure 11 illustrates the steps taken when this error occurred.

In one separate instance, the ACK key was pressed prior to selecting a waypoint category when the "Undefined Leg" screen was displayed. This occurred on the first trial of the second Test Day and was clearly a result of forgetting. The subject reported having difficulty remembering how to begin the programming process. The "Saved Position" message was displayed and the subject recovered by randomly turning knobs and pressing keys until the message was erased as described below.

For all occurrences of this error, high levels of confusion were observed and subjects were unsure of how to recover. This was evident by noting that every case involved random control manipulations prior to recovery. The only way to recover was to press ACK one time after the "Saved Position" message was displayed. This occurred twice with a mean recovery time of 126.5 seconds (see steps 1-4 and 9 of Figure 11). For the remaining trials, ACK was pressed multiple times and multiple "Saved Position" messages occurred prior to recovery (see steps 1-9 of Figure 11). The mean recovery time for the multiple occurrences was 175.0 seconds.

3.5 POST-EXPERIMENT QUESTIONNAIRE

The specific responses for each question are shown in Appendix H, a summary is provided below.

Question 1 asked subjects to describe the programming procedure(s) that were found to be most confusing. One subject responded that it seemed easier to misidentify waypoints during editing. One subject responded that better layout of the LED display was needed, and three subjects replied that nothing was confusing.

Question 2 asked subjects to describe the single best feature of the GPS/LORAN. Three subjects responded that the "Direct To" navigation feature was very usable enroute and faster with which to navigate. One subject replied that the brightness of the display was advantageous.

Question 3 asked subjects to list the single worst feature of the GPS/LORAN. One subject responded that the time required to scroll a waypoint was a problem. Two subjects replied that signal strength in precipitation could be a problem.

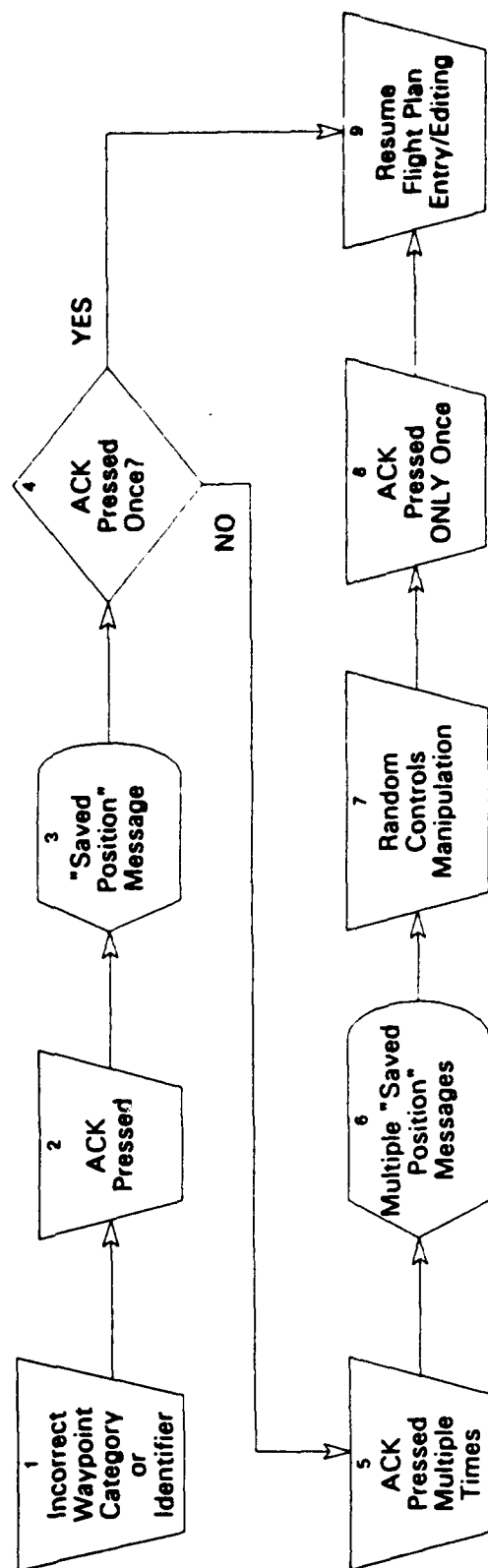


FIGURE 11. ACKNOWLEDGE INVALID WAYPOINT ERROR

Question 4 asked subjects if they experienced difficulty with information retrieval. One subject replied that a larger, better spaced-display would help. One subject responded that several waypoints were not in the database as shown on the experimental flight plans. Three subjects responded that no difficulties were experienced with information retrieval.

Four of five subjects replied that the programming logic corresponded with the way that they think about and follow a flight plan (Question 5). One subject was unable to evaluate this question because the GPS/LORAN was not used for actual course guidance.

Question 6 asked if subjects usually follow a flight plan or if navigation is accomplished by flying waypoint to waypoint. Two subjects reported flying waypoint to waypoint and one subject replied that a flight plan was usually followed. Two subjects responded that they do not usually fly with a GPS/LORAN.

Question 7 asked subjects to rank order the navigation information that should be displayed at all times. The specific rank order of responses is provided in Appendix G. The most frequently requested information was time and distance to a waypoint ($n = 5$), followed by the display of crosstrack error ($n = 3$), and the current waypoint navigating to ($n = 3$). The need for waypoint alert information, ground speed, course to fly, and an indication that the receiver is working were each reported once.

Question 8 asked subjects to provide design recommendations according to the knobs/keys, labeling, displays, and procedures of the GPS/LORAN. Two of the five subjects provided input. With respect to knobs and keys it was suggested that large keys, that "beep" when pressed, would be advantageous. One subject replied that more characters should be skipped as the knob is turned faster during scrolling operations. With respect to labeling, larger and better lighted labels were recommended. Both subjects recommended a larger display. One subject replied that the LED "dots" tended to smear and suggested the use of an LCD or plasma display. One subject suggested that a space was needed between the five character identifiers and the word "ACK?" of the secondary display. No procedural changes were suggested.

3.6 GENERAL COMMENTS

In addition to the post-experiment questionnaire, subjects' general comments were recorded during each session. These comments were grouped according to three categories: 1) GPS/LORAN, 2) SIMULATOR/APPARATUS, and 3) EXPERIMENTAL TASK. The specific comments are provided in Appendix I, a summary is provided below.

Comments grouped in the GPS/LORAN category concerned the knobs/keys, system logic, and display characteristics of the receiver. The most frequent response was that the waypoint "CDI#1" was confusing because NDB's usually contain only three characters ($n=2$). This waypoint was viewed by all subjects and was a valid database entry. The GPS/LORAN was

rated as confusing because there were many functions, and because of the primary and secondary displays/controls delineation. The keys were viewed as being too small and difficult to press. The position of the GPS/LORAN was viewed as being potentially problematic during turbulence conditions of real flight because the display was small.

Comments grouped in the SIMULATOR/APPARATUS category focused mainly on the flight simulation dynamics. Nine responses were made that portrayed the simulation dynamics as poor. Seven of these responses were made during the training session and two were made during Test Day 1. One comment that the simulator "feels closer to full-scale real" was made during the first test session. Two subjects reported that the position of the GPS/LORAN caused arm/shoulder fatigue.

Comments grouped in the EXPERIMENTAL TASK category focused mainly on the demands of the flight/program conditions. Three subjects rated the flight/program task as difficult to perform. One subject developed a strategy to cope with the simulation dynamics in which the programming task was entered as a series of sub-tasks rather than one large task. One subject reported a general strategy in which different waypoint entry methods were used depending upon the waypoint category. For NDB and INT waypoints, cursor entry was used and scrolling was used for the remaining categories because fewer APT, VOR, and USER categories existed in the database.

4. DISCUSSION

4.1 PILOT FLIGHT AND GPS/LORAN EXPERIENCE

The subjects' flight experience data indicate that subjects had a wide range (300 to 21,000 hours) of overall flight experience. Subjects' also had a wide range of total IFR time (60 to 700 hours) indicating that relatively low and high IFR experience pilots participated in the study. Most subjects gained their experience in a general aviation environment flying many types of single-engine aircraft. Overall, the subjects of the present study had a good amount of general aviation experience and were fairly experienced under IFR flight conditions.

Three of the five subjects had prior experience with a variety of LORAN receivers. Previous LORAN use during flight was moderate with a median estimate of 45%. The display readability and the overall usability of all receivers were rated as no worse than "easy." This indicates that subjects were satisfied with their previous LORAN receiver experience. Flight plan creation and editing for one receiver were rated as "somewhat difficult"; these functions for all other receivers were rated as "easy." Two subjects rated error recovery as "very easy"; one subject rated it as being "neutral." Controls operation ratings for all receivers ranged from "easy" to "neutral."

Only one subject reported that receiver usage caused a brief distraction from the primary flight duties. The "Direct-To-Waypoint" procedure of one receiver was described as difficult to remember. Suggestions for improvements of one receiver focused on the need for better operations and training documentation. This suggestion supports concerns that have been raised by pilots. Previous studies indicate that better GPS/LORAN documentation is strongly needed for pilots and flight instructors (Adams et al., 1992). These authors report that pilots rated operations manuals and training materials as being poorly organized for effective usage. Furthermore, training materials were described as lacking in that they do not convey a good understanding of system function.

4.2 FLIGHT PERFORMANCE

In general, crosstrack performance was good for all single task conditions (see Figure 5). Single task RXTK performance improved for the low and high turbulence conditions across session. The best single task performance occurred during the warm-up trials of the second test session. These data indicate that subjects maintained their manual flight skills after a test interval of at least seven days. The effect of programming on flight performance is shown by the increase in crosstrack error for all dual task (flight/program) trials relative to single task performance. Although performance was degraded for these trials, the variability in performance during training diminished by the end of the first test session. Performance across test session was maintained after a test interval of seven days, indicating that subjects were performing the flight task as instructed.

Altitude deviation performance showed a trend similar to the RXTK scores (see Figure 6). Single task RADV scores were maintained at less than 23 feet of deviation for all conditions, and appeared to be stable across session. Dual task performance improved consistently for the medium and high turbulence conditions and remained stable for the low turbulence condition across session.

In summary, learning effects appeared to diminish by the end of the first test day for both flight performance measures. Subjects were able to maintain altitude performance within the instructed range of ± 100 feet for the single and dual flight task conditions. Programming the GPS/LORAN caused flight performance to degrade for all conditions.

4.3 ERROR-FREE GPS/LORAN PROGRAMMING PERFORMANCE

Subjects were in general, very accurate at the programming task. Eighty-seven percent of the trials were performed without an error. In general, subjects required more time to complete the programming task as turbulence increased (see Figure 7), suggesting that the flight task was sufficiently demanding. A slight test interval effect was found for overall programming time in which more time was required at the high turbulence level of the second day. There were no appreciable differences for turbulence or test interval when programming time was examined by task phase (see Table 4). A trend was found that suggested subjects were slightly quicker at the accuracy checking task during Test Day 2.

The high accuracy rate and lack of a large test interval effect shows that subjects were trained well and maintained their procedural skills over at least a seven day period. In addition, this suggests that the programming task may have been too easy.

4.4 GPS/LORAN PROGRAMMING ERRORS

Errors in programming performance occurred on only 13% of the trials (see Table 5). Although the number of errors committed was small, they were apparently effects of turbulence and task. For turbulence, the number of errors increased as turbulence increased from low ($n=3$) to medium ($n=6$) to high ($n=7$). This suggests that less attention may have been available for the programming task at the higher turbulence levels. With respect to task phase, more than twice as many errors occurred during flight plan entry ($n=11$) compared with flight plan editing ($n=5$). This suggests that flight plan entry may have been more difficult than the flight plan editing. One explanation for this finding is that the entry phase required the entry of four waypoints while the editing phase only required two waypoint entries (see Figure 4). In addition, a single key press was required to complete the delete portion of the editing phase once the waypoint was positioned on the primary display.

The lack of a test interval effect could be due to two factors. It was speculated that the programming task may have been too easy because the flight task did not require the use of

the GPS/LORAN receiver. In addition, two thirds of the training trials involved the programming task, suggesting that subjects were highly trained. Therefore, any test interval effects may have been masked by the current experimental design. While this may be the case, the specific errors and recovery processes that were observed do provide useful and relevant information concerning the programming logic and interface attributes of the GPS/LORAN receiver.

Only the Misspell Waypoint error did not involve a recovery process. In this case, an incorrect waypoint was entered into the flight plan and was not corrected because the error was not noticed. In part, the error may not have been detected because the incorrect waypoint (JIMMI) was phonetically similar to the desired waypoint (JIMIE). Secondly, the receiver logic accepted "JIMMI" into the flight plan because it was contained in the database. Lastly, the waypoint was deleted from the flight plan as part of the editing portion of the programming task. Because of these factors, subjects were unaware of the error and did not initiate a recovery. This presents a unique problem in that, both the operator and the system were functioning as if there was no problem. The system accepted the waypoint because it was valid according to the database and the pilot thought that a correct waypoint was entered. It is likely that this error might have been noticed only after flying off-course toward the incorrect waypoint. This is an example of a system that lacks a "reality check" for input data, and has the potential to seriously degrade flight performance and safety (Adams et al., 1992; Wiener, 1985).

The remaining three error types were recognized by subjects and involved a recovery process. The ease or difficulty of recovery depended upon the "depth" of the programming sequence at which the error occurred. Errors that were recognized early in the programming process were easier to recover from than errors that occurred "deeper" in the process. A second distinguishing characteristic was whether or not the error involved the manipulation of the acknowledge (ACK) key. The Select Incorrect Waypoint Category error did not involve manipulation of the ACK key (compare Figures 9, 10, and 11) and subjects recovered quickly and easily. The recovery method involved exiting and entering flight plan mode by turning the large, primary control knob. Subjects were able to continue the programming process, relatively unaffected by the error.

The two remaining error types involved activation of the ACK key at some point during the programming process. The specific point at which ACK was pressed determined the type and severity of the error and appeared to impact recovery as well. In general, these errors were more difficult to recover from and required long recovery times. One of these errors was the Default Waypoint Entry error.

The Default Waypoint Entry errors occurred when ACK was pressed after a waypoint category was selected but prior to entry of an identifier. Because an identifier was not entered prior to pressing the ACK key, the system logic selected the default waypoint of the current category. In only one case, recovery from this error was initiated immediately and the subject deleted the unwanted waypoint from the flight plan (see steps 1-5 and 10 of

Figure 10). The remaining four occurrences involved multiple ACK presses and random control inputs before subjects successfully deleted the incorrect waypoint (see steps 1-4 and 6-10 of Figure 10).

Why do subjects press the ACK key at the improper time in the programming sequence and enter the default waypoint? One contributing factor is the multifunction characteristic of the ACK key. This key is used for many purposes: 1) To begin the flight plan process, 2) to enter waypoints into a flight plan, 3) to advance to the next position in a flight plan in order to enter another waypoint, and 4) to accept editing functions. As a result, subjects become accustomed to pressing the ACK key any time it flashes without determining the consequences beforehand.

A second factor is that the status of the ACK key does not change once a waypoint has been entered--it continues to flash. This design characteristic was problematic because subjects could not remember if ACK was pressed or needed to be pressed in order to proceed with programming. This was evident in subjects behavior after switching attention to the programming task from the flight task; the tendency was to press ACK upon returning attention to the receiver. This is clearly an example of a design-induced error that should be addressed in future receiver designs.

Recovery from the Default Waypoint Entry error was affected by the layout of the editing functions. In order to reach the editing functions, the large, secondary knob must be turned until the insert, delete, change, or erase screens are shown. If the secondary knob was turned in the appropriate direction, these functions were shown in a serial order. If the knob was turned in the opposite direction, four screens of unrelated information (e.g., TRSA/ARSA notices, distance and bearing to waypoint) are shown. This unrelated information is located within the first two detents of the waypoint entry screens and subjects would often turn the knob in this direction. Upon seeing this information subjects had a tendency to become confused and would not turn the knob in the opposite (i.e., appropriate) direction. Stated another way, subjects did not realize the editing screens were within three or four detents of their current position and were not sure where to find them. This caused confusion and lengthened the recovery process.

The Acknowledge Invalid Waypoint error is different from the Default Waypoint Entry error in that the identifier entry process was started before ACK was pressed (see Figure 11). If the category or identifier name was incorrect and the waypoint was not contained in the database, pressing ACK produced a "Saved Position" message. Because the waypoint is not in the database, the ACK key did not flash and the "ACK?" message on the secondary display did not appear. Once the "Saved Position" message appears, the ACK key is illuminated (but does not flash) until the "Saved Position" message was cleared. The only method of recovery was to press ACK once. This action returned the screen to the previous mode but did not return the user to the exact previous state (i.e., previous, incomplete waypoints are deleted).

Because this error can only occur when ACK is truly pressed at "the wrong time" (i.e., not flashing), it is likely that subjects pressed ACK out of habit. As described earlier, subjects were accustomed to pressing ACK due to the multifunction nature of the key (at least two presses are required for each waypoint entry). As a result, they may simply press ACK when in doubt or simply due to habit. The primary source of difficulty associated with this error was the inability to initiate a recovery sequence in a timely manner.

Essentially, subjects were confused about the "Saved Position" message and were unsure of how to proceed when it was displayed. Because the ACK key remained illuminated after the error occurred, subjects were not sure if it should be pressed again. The steady, lighted ACK key was a condition that subjects had only encountered during the initial training (see Appendix C, p. C-6). To further complicate matters, subjects were reluctant to press ACK in order to clear the message although this was the only recovery method. Turning any knob (except the power knob) or pushing any key (except ACK) did not produce a response in the receiver, and subjects may have perceived that the system was "locked-up." This system behavior combined with the uncertainty caused by the steady illuminated ACK key, served to confuse subjects and lengthen the recovery process. Evidence of this behavior is found in that all recoveries involved random control manipulation. In one case, a subject became so frustrated that receiver power was turned "off" in order to reset the receiver.

4.4.1 IMPLICATIONS FOR TRAINING

The random behavior observed during error recovery suggests that formal training materials (e.g., operations manuals) should include explicit error recognition and recovery information. In general, GPS/LORAN operation manuals do not include information about errors or specific methods of recovery. It is also likely that pilots are not trained by instructors in how to recognize and/or recover from errors. As a result, it is possible that the confusion and multiple errors that occurred in the laboratory may occur in actual flight. Clearly, some form of initial training along with the appropriate documentation could in part, reduce error recognition and recovery problems.

4.5 POST-EXPERIMENT QUESTIONNAIRE

One of the main purposes of the post-experiment questionnaire was to capture subjects' concerns about the GPS/LORAN receiver. Of all comments that were received, only four were directly related to the errors that occurred. The low number of comments related to errors suggests that subjects were unaware of why the errors occurred. In addition, subjects may also have been unaware that system logic, prompting, and other system attributes can contribute to performance decrements.

Four of five subjects replied that the program logic corresponded with the way that they think about and follow a flight plan. The low number of errors supports this finding,

however, subjects showed high levels of confusion and frustration when errors occurred. This dissociation between performance and subjective ratings provides support for the notion that subjects were unaware that receiver design can adversely affect performance. This finding also provides support for the use of both objective and subjective measures to evaluate pilot-receiver performance issues (see Yeh & Wickens, 1988).

One subject commented that it seemed easier to misidentify waypoints during editing. Part of the confusion may be due to the layout of the flight plan instructions. More text was required for the editing instructions compared with the entry instructions (see Appendix B). This additional text may have been more difficult to interpret and could have caused confusion among the waypoints. In addition, the organization of the editing screens may have contributed to this comment. Confusion during recovery from the Default Waypoint Entry errors occurred when subjects viewed unrelated information (e.g., TRSA/ARSA notices, distance and bearing to waypoint) while searching for the editing functions. Because unrelated information was present at the same level as the editing functions, subjects were unsure of their location within the system structure and were likely to become lost.

One subject replied that the time required to scroll a waypoint was a problem. A related comment suggested that the amount of data that is skipped should be a function of knob speed. This explains why most subjects used the faster, "cursor" method for entering waypoints. The problem with this approach is that it allows for the occurrence of Invalid Acknowledge Waypoint errors. That is, invalid waypoint identifiers can only be entered on the secondary display using the cursor method. If scrolling is used, only valid waypoints are displayed on the screen and it is impossible to enter an invalid waypoint.

It was commented that several waypoints were not contained in the database as given in the flight plans. Actually, the waypoint identifiers were spelled correctly but the wrong categories were chosen. As a result, Acknowledge Invalid Waypoint errors occurred and subjects were unaware of the reason why. There are two factors that contribute to the difficulty of recognizing and verifying waypoint categories. Subjects' hands often blocked the view of the category designator and subjects were often required to release the secondary knob to visually inspect the category. In addition, the category designator was only displayed on the primary display after a waypoint was entered. At this point, it was too late to simply change the category--the waypoint must be changed or deleted and re-entered into the flight plan.

One comment that did not appear to relate to any specific error but may have caused confusion referred to the lack of space between the five character identifiers and the word "ACK?" on the secondary display. This is purely a software issue in that the display space exists, but the design failed to take advantage of it. Other comments that might have been indirectly related to poor performance included the need for: larger and more generously spaced display(s), better layout of the display(s), larger keys, keys that "beep" when pressed, and larger and brighter lighted labels.

4.6 GENERAL COMMENTS

One subject replied that the GPS/LORAN functions were confusing because there were many available. In addition, the primary/secondary organization of controls and displays also added to confusion about system operation. A related concern was that there were many different ways to perform the same function. This was perceived to produce confusion about remembering specific procedures. The complexity of GPS/LORAN receivers has been a strong concern among users, particularly under periods of high workload (Adams et al., 1992). These comments support previous findings that point to non-intuitive and complex system structures as the primary cause for errors. Because these systems provide many ways of attaining the same goal, users may not formulate an appropriate mental model of the system. Hence, when trouble arises, pilots may be unsure about the proper recourse.

A majority of the comments related to the simulation focused on the flight dynamics. Seven comments about the instability and unresponsiveness of the flight simulation were made during the training session. During the first test session, one comment echoed these concerns and another claimed that the simulation was operating more closely to real flight conditions. During the second test session, one subject replied that the simulation was responding too slowly. The decline in the frequency of these comments across session suggests that subjects learned how to more effectively interpret and respond to the flight simulation.

Comments about the experimental conditions show that subjects perceived a great deal of demand associated with the flight/program dual task trials. Two subjects reported that specific strategies were developed to compensate. To assist with time-sharing, one subject reported that it was easier to program/edit the GPS/LORAN as a series of sub-tasks. Another subject used different waypoint entry methods depending upon the type of waypoint category that was required. This subject reported that it was faster to scroll airports and VOR's because fewer identifiers are in the database compared with NDB's and INT's. The cursor method was used to enter NDB or INT waypoints. The fact that strategies were developed suggests that subjects were developing internal models of system function that correspond to the GPS/LORAN receiver logic and menu structure.

4.7 SUMMARY

The flight performance data indicate that subjects performed the task as instructed and were able to maintain their manual flight skills after a period of at least seven days. Turbulence effected the programming task as predicted in that more time to program was required as turbulence was increased. In addition, more complex errors were committed at the medium and high turbulence levels. The lack of a marked test interval effect could be due to the fact that subjects were highly trained and the programming task may have been too easy. The programming task involved a high degree of procedural knowledge and subjects were not required to use any of the receiver functions in order to fly the simulation. Hence, subjects

treated the programming task almost as a separate task altogether rather than an embedded task which could have made the task easier to perform. Evidence of this is given in that strategies were developed to enhance either the programming task or the flight task. Although the programming task is similar to enroute programming conditions, it does not require subjects to integrate the GPS/LORAN functions with the flight task and might not have been sufficiently demanding.

The strategies developed by subjects suggests that mental models (e.g., Reigeluth & Schwartz, 1987; Rouse & Morris, 1986) were developed by subjects in an attempt to better understand the system logic and menu structure. Difficulties were found with the editing functions and could be due to the extraneous information that was contained among the editing commands. Because subjects became easily confused when unrelated information was viewed, it is increasingly important to determine how menu structures affect performance both within and across GPS/LORAN receiver types.

The Misspell Waypoint error may appear to be non-critical, however, its occurrence during actual flight and in the presence of stressors (e.g., traffic, weather, abnormal/emergency operations) could compromise flight safety. Thus, current GPS/LORAN systems must be evaluated according to how well pilots can perceive errors. Comments from this study indicate that pilots were, in most cases, unaware of incorrect actions that were performed. In addition, the random behavior exhibited during recovery indicates that pilots were also unsure of how to recover in an orderly fashion.

The present research indicates that errors can occur under fairly simplified flight conditions. Although few errors were committed overall, the fact that they did occur while a simple navigation task was performed (straight and level flight) suggests the potential for more serious problems under actual flight conditions. As GPS/LORAN receivers are accepted into precision navigation tasks (e.g., to replace or augment ILS) the flight demands will be high and new problems in pilot/receiver performance are likely to emerge. Hence, receiver designs of the next generation must provide more intuitive interface designs by considering the pilots' ability to operate within the menu structure and to recognize and recover from errors when mistakes are made.

4.8 FOLLOW-ON RESEARCH

Follow-on research needs to be conducted to validate the present concerns and evaluate the design attributes of additional GPS/LORAN receivers. Future evaluations should also consider the context in which receivers will be used to navigate within the National Airspace System. The cognitive demands associated with enroute and terminal operations are different and receiver designs should be evaluated in both contexts. Terminal procedures for example, may require that pilots choose one of several pre-determined approach procedures for landing. Will the receiver sequence the pilot through the approach automatically or will the pilot be able to choose waypoints within the pre-determined approach? What are the effects

of air traffic control (ATC) changes? Can pilots quickly and accurately adjust the pre-determined approach sequence as needed? In addition, pilots are likely to be sequenced into the approach path at various points depending upon traffic. As a result, the manner in which a receiver allows the pilot to enter the approach at different points will be critical. A related concern is the missed approach procedure. Will the missed approach procedure (MAP) be pre-programmed or will the pilot be required to program the MAP as part of the approach duties? How will required changes in the MAP be accommodated when weather or traffic are encountered?

The enroute duties also need to be further evaluated. The present study examined only the straight and level flight duties required of enroute operations. In addition, the different demands associated with IFR and VFR flight are likely to affect programming performance. What are the effects of ATC commanded flight plan changes while enroute? Can pilots effectively monitor radio communications, navigate within the required airspace corridors, avoid traffic, and make program changes simultaneously? The current receiver designs must be evaluated under the above conditions to determine which design attributes facilitate performance and which have the potential to degrade performance. The favorable design attributes can be used to influence the next generation GPS/LORAN receiver designs.

4.9 IMPLICATIONS FOR GPS/LORAN RECEIVER DESIGN

The following design recommendations are based on programming performance, subjective responses, experimenter observations, and the relevant literature. The General Recommendations section is related to improving the overall usability of GPS/LORAN receivers. The following sections address specific controls, functions, system logic, error recognition, and error recovery issues.

4.9.1 GENERAL RECOMMENDATIONS

Perhaps the simplest and most overlooked design attribute is the need for a backspace, escape, or clear key. Whatever the function, pilots must have the ability to correct data entry mistakes quickly and easily. The use of a backspace, escape, or clear key could facilitate performance by reducing "restarts" in programming because of simple data entry mistakes.

Some pilots stated that display character spacing was problematic. Mangold, Eldredge, and Lauber (1992) suggest a minimum separation of one character space between words or distinct display segments. A related concern is the minimum character height required for text readability. Characters and labels subtending at least 30 minutes of visual angle for critical information and 20 minutes of visual angle for non-critical information is suggested (Mangold et al., 1992). At the viewing distance of the present study, minimum character

heights of 0.23 inches (critical information) and 0.15 inches (non-critical information) are suggested. These measurements require validation under turbulence and vibration conditions.

Because lighting conditions vary between extremes during flight, it is desirable to provide user controllable lighting. Mangold et al. (1992) report contrast ratios of 10:1 for indirect ambient lighting and 20:1 for direct ambient lighting conditions.

Because pilots may not always be able to view an actual key press, it would be advantageous to provide confirmation of key presses. One pilot suggested that the keys "beep" when pressed to provide feedback; McCormick and Sanders (1982) suggest audible "clicks." As McAnulty (1993) points out, auditory signals may not be the best choice in a cockpit environment because of high ambient noise levels. As an alternative, tactile feedback can be used to provide information that a key has been pressed. Tactile feedback may help support time-sharing because it does not increase the visual demands associated with flight.

Scrolling speed of characters was mentioned as a concern by one pilot. It seems intuitive that character scrolling speed should ramp-up (to some limit) as knob speed increases to reduce the amount of time required to enter waypoints. An algorithm of this type should allow users to input large changes with large knob turns and "tune-in" closer and closer to the desired target with smaller knob turns. A related concern is maintaining consistent and efficient control manipulations. For example, continuous knob turns should cause the entire alphanumeric database to repeat as the last character is passed. Some systems contain a "stop" point, in which the user must scroll in the reverse direction to reach the beginning of the database. This design requires large amounts of knob turning and is not an efficient design choice.

Additionally, key sizes were remarked as being too small and difficult to operate. McCormick and Sanders (1982) suggest a minimum key size of 0.5 inches and at least 0.5 inches of separation between keys for fingertip operation. McAnulty (1993) reports that minimum key sizes between 0.385 and 0.50 inches, with a minimum separation of 0.25 inches, should suffice.

4.9.2 DEDICATED FUNCTIONS

A dedicated function is defined as an action that is required to be available at all times (regardless of the current mode), and may also require a single key press/knob turn to activate. This type of function should have a distinct control that is not shared by other functions or modes. In addition, if the function is very easy to activate (e.g., a single key press), it should require a confirmation step to reduce unwanted activations. Users should also have the ability to "escape" or "back-up" within a process if an unwanted activation occurs.

4.9.3 MULTIPLE FUNCTION CONTROLS

A multiple function control is defined as a control that activates different functions depending on the system mode. Multiple function controls are problematic because they contribute to confusion, errors, and inappropriate control manipulations. To reduce the problems associated with multiple function controls, users should be clearly aware of what a control will do in any given mode (Hutchins, Hollan, & Norman, 1986). One method of achieving this is to provide appropriate display prompts. For example consider key XYZ: in one case this key accepts a waypoint into a flight plan, while in another case it advances the active position within a flight plan. Display prompts such as "Press XYZ to add waypoint" and "Press XYZ to advance," respectively, could reduce the likelihood of confusion and control errors. Although the specific content and length of messages would need to be determined and evaluated, the idea is to provide the user with unambiguous, easy to interpret information about the effects of a control manipulation for each system mode.

4.9.4 SYSTEM LOGIC AND MENU STRUCTURE

System logic and structure issues refer to the organization of the various menus, pages, or screens of display information that are contained within a particular mode. Although research is required to determine the exact structure and layout for the specific system modes, some generalizations can be made. Information that is unrelated to the purpose of the mode (i.e., the task) should not be contained within that mode because of the potential for confusion. For example, TRSA and ARSA information should not be included at the same level as flight plan editing commands. Modes should also contain instructional prompts that convey the state of the mode to the user. This feature could reduce errors associated with the memory and divided attention limitation of human operators (Miyata & Norman, 1986). For example, flight plan modes should contain distinct "begin" and "end" points, as well as prompting to guide the user through each stage of the flight plan entry process (e.g., Enter Waypoint?, Edit Waypoint?, and Flight Plan Complete?). These attributes may make it less likely for pilots to forget or misinterpret *what has* and *what needs* to be accomplished while time-sharing receiver programming with other flight duties.

Research is required to determine the optimal logic structures for the various modes of GPS/LORAN receivers. One approach is to design the logic structures according to the duties for each phase of flight (Adams et al., 1992). This implies that some modes may function differently across a particular flight. How will pilots respond to these differences? What happens when well-learned procedures require "new" actions? Can errors be easily recognized and recovered from in each mode? These concerns need to be addressed in order to evaluate the impact of designing by phase of flight.

4.9.5 ERROR RECOGNITION AND RECOVERY

Typically, error recognition and recovery is accomplished by comparing the intended result of an action with the actual result. For this to occur, the user must understand the logic and menu structure of the system, how to operate the controls (multiple and dedicated function controls), and the relationship between the controls and system logic (Lewis & Norman, 1986). Pilots in the present study experienced difficulty in at least one or all of these areas when an error occurred. The design recommendations made in the above sections serve to improve the users' ability to evaluate the intended and expected actions, and therefore improve error recognition and recovery. In addition, it is important to consider the need for providing redundant error recognition and recovery information.

One method of providing redundant error information is to "alert the user" via the display or other media that something was done incorrectly. Although it is impossible to predict all possible errors, consideration of display prompts for disastrous errors would be advantageous. For example, the user could be alerted if the category or identifier of a desired waypoint does not exist in the database. A message such as "Waypoint Does Not Exist, Create?" would prompt the user to check the spelling and edit the waypoint, or accept it as is.

Users should also be alerted about similar waypoints that exist in the same or different categories. For example, user waypoints that sound the same (e.g., DREEM vs. DREAM and JIMIE vs. JIMMI) could easily be transposed within a flight plan. To avoid confusion the user could be given both waypoints and prompted to choose the correct one (e.g., "DREEM or DREAM?"). Waypoints of different categories that are spelled the same (ONA-airport and ONA-VOR) may also be easily confused. An obvious factor is the spelling (some receivers add a K to the beginning of all airports to avoid this problem), however a related concern is the physical layout of the category selector. Because the airport and VOR categories are more frequently used, they are located adjacently on most receivers. This also affords the accidental incorrect selection of categories. Separation of the categories and providing large category identifiers could minimize this concern.

Like the system logic and menu structure issues, error recognition and recovery methods need to be developed and tested. This study shows that current display and logic configurations do not always promote easy recognition and recovery of errors. In some cases, multiple errors resulted because pilots were unsure of what to do or why an error occurred. Clearly, these problems must be minimized to ensure the safe and effective use of GPS/LORAN receivers in precision navigation tasks.

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APPENDIX A
FLIGHT INSTRUMENT DESCRIPTION

FLIGHT INSTRUMENT DESCRIPTION

Flight Instruments

(Clockwise from lower left corner of Figure 2)

(Primary instruments in bold)

Automatic Direction Finder (ADF)

This instrument has a rotatable compass rose dial and a needle that indicates the relative bearing of the NDB (non-directional beacon) station from the aircraft. This instrument will be inoperative (INOP) during the experiment.

Turn Coordinator

The single hash marks on the right and left side indicate that the aircraft is in a "standard rate" ($3^\circ/\text{second}$ or $360^\circ/\text{two minutes}$) turn. Displacement of the "ball" indicates an uncoordinated turn that can be corrected by applying rudder of the same side as the ball (i.e., step on the ball). This instrument is operative (OP) during the experiment.

Airspeed Indicator

The speed of the aircraft is displayed as indicated airspeed (IAS) in knots (kts). The indicator has three colored bands and a red marker. The green band is the normal operational speed range, and the white band is the allowable flaps operation range, the yellow band is a caution range, and the red mark is the never exceed speed. The lowest point of the white range is full flaps stall speed. This instrument is OP during the experiment. Each trial will always begin at approximately 100 kts airspeed and will vary throughout a trial depending on aircraft attitude. **DO NOT ATTEMPT TO ADJUST AIRSPEED USING THE THROTTLE CONTROL.**

Outside View Display

This display represents the out the window view and will remain gray during the entire experiment to simulate instrument meteorological conditions (IMC). This instrument is OP during the experiment.

ADF Tuner

The lower left instrument is the ADF tuner and will be INOP for the experiment.

Magnetic Compass/Marker Beacons

The magnetic compass is shown in the upper portion of this display and is OP during the experiment. This instrument behaves like a "real" compass and therefore is vulnerable to lead, lag, dip, acceleration, and oscillation errors due to flight attitude; it is best not to rely on the compass for heading information.

The lower portion of this instrument displays the outer, middle, and inner marker beacon annunciators. This instrument will be INOP during the experiment.

Navigation Radio (NAV) Cluster

The upper and lower instruments display the navigation aid frequencies that are tuned in. The upper navigation radio (NAV1) is tuned to a VOR and displays distance (DME) information. This instrument is preset and will not require adjustment during a trial. **DO NOT ATTEMPT TO ADJUST THE NAV1 RADIO.** The NAV2 (lower unit) radio is INOP during the experiment.

Tachometer

This instrument shows the number of engine revolutions per minute (RPM). Each trial will begin at approximately 2400 RPM and will vary according to aircraft attitude. **DO NOT ATTEMPT TO ADJUST THE RPM's MANUALLY.**

Fuel Cluster

The left and right fuel cell capacities are shown and will always begin at full for each trial. This instrument is OP during the experiment and will decrease as flight time increases.

Engine Instruments

Cylinder head temperature (CHT), exhaust gas temperature (EGT), oil pressure (OIL P), oil temperature (OIL T), and an ammeter (AMP) collectively display engine status. All instruments are OP during the experiment.

Clock

A clock displays elapsed time for each trial.

Throttle Cluster

The three knobs indicate throttle position (left side), mixture, and propeller settings (right side) and will not require adjustment during the experiment. **DO NOT ATTEMPT TO ADJUST THE THROTTLE DURING THE EXPERIMENT.**

Elevator/Trim/Flap Position Indicators

The elevators, trim, and flap settings are shown in this display. The small left hash mark displays elevator displacement (up or down). The triangle indicator shows the elevator trim setting, and the right knob shows flap position. The trim and flap positions are preset and will not require adjustment during the experiment. **DO NOT ATTEMPT TO ADJUST THE TRIM AND FLAPS DURING THE EXPERIMENT.**

Gyro Compass/Directional Gyro

This instrument provides more accurate heading information than the traditional magnetic compass. However, this instrument is vulnerable to precession over time

and cannot be adjusted to compensate. Do not use this instrument for precise tracking information.

Attitude Indicator

Aircraft pitch and bank are shown with this instrument. The vertical hash marks are graduated in 5° increments for pitch. The bank index (outer circle) is graduated in 10° increments up to the first 30° of bank, and in 30° increments for up to 90° of bank. The blue portion of the indicator indicates the direction of the sky and the gray portion indicates the earth relative to the aircraft attitude.

Altimeter

This instrument shows aircraft altitude (above sea level) and is preset at 5000 feet for each trial. The barometric pressure is preset at 29.92 and does not require adjustment. **DO NOT ATTEMPT TO ADJUST THE ALTIMETER DURING THE EXPERIMENT.**

VOR1/VOR2

The number one VOR (V1) is operational and the course deviation needle (CDI needle) should be used for primary tracking information. The CDI needle will be displaced toward the left or right depending upon aircraft heading relative to the tuned in course. **DO NOT ATTEMPT TO ADJUST THE VOR DURING THE EXPERIMENT TO COMPENSATE FOR COURSE DEVIATIONS, FLY THE AIRCRAFT TO MAINTAIN A CENTERED CDI NEEDLE.** The second VOR (V2) is INOP during the experiment.

Vertical Speed Indicator

This instrument indicates the rate of climb and descent in hundreds of feet per minute. This instrument is OP during the experiment and will vary according to aircraft attitude.

APPENDIX B
SAMPLE FLIGHT PLAN

SAMPLE FLIGHT PLAN

PROGRAM SEGMENT

Flight Plan 1:

Waypoint	Category
GFL	APT
PONDS	USER
SXD	NDB
EEN	VOR

EDIT SEGMENT

INSERT SHERY USER BETWEEN GFL APT AND PONDS USER

DELETE PONDS USER

CHANGE SXD NDV TO KHRIS INT

ACCURACY CHECK SEGMENT

GFL	APT
SHERY	USER
KHRIS	INT
EEN	VOR

Note: Underlined descriptions not included on experimental flight plans.
The accuracy check segment was printed on the reverse side of the page.

APPENDIX C
RECEIVER OPERATING INSTRUCTIONS

RECEIVER OPERATION TRAINING

I. Overview

The purposes of this experiment are to determine how long a person retains the knowledge required to operate a GPS/LORAN receiver, to identify the GPS/LORAN operations that are most prone to error and to identify the types of errors that are made while performing GPS/LORAN operations. First we will teach you how to operate a GPS/LORAN receiver and allow you to practice using it. Tomorrow will be the first session in which you will perform a series of operations and we will record the time needed to perform these operations as well the number and types of errors you might commit. The second session will be in 1 or 2 weeks.

The first step is to train you to operate the GPS/LORAN. If you have any questions during the training, don't hesitate to ask. You may end your participation in the experiment at any time. As you read these instructions, you will notice that examples of specific programming procedures will appear in bold text.

II. Waypoints and GPS/LORAN

Only if questions are asked:

First I would like to familiarize you with some of the terms I will be using to explain GPS/LORAN navigation. VORs are radio beacons that transmit beams called radials outward in every direction. A receiver in the airplane detects these signals and indicates the radial on which the aircraft is located, thus allowing a pilot to follow a radial to or from a VOR. NDBs are radio beacons like VORs but they are nondirectional, that is they do not transmit radials. An intersection is the point where radials from two or more VORs cross.

Waypoints are points on the ground specified by coordinates of latitude and longitude. They may be airports or other navigational aids such as VORs, NDBs, radial intersections or other locations specified by the user.

The GPS/LORAN is used to 1) store the locations of these waypoints as well as their names, or identifiers; 2) to store the waypoints in a prearranged order called a flight plan; and 3) to provide navigational information to the pilot during flight.

Among the operations that I will teach you are: how to create and edit a flight plan, how to create your own waypoints and save them, and how to view navigation information.

III. Database

This receiver has an internal database of over 20,000 waypoints. The database is divided into 5 categories: APT, NDB, INT, VOR, and USER. The first four are for storage of airports, NDBs, intersections, and VORs respectively. The USER category is for storing in the database any additional waypoints that you specify.

The database in this receiver may contain more information about a waypoint than its name and position. For example, if you look at one of the airport waypoints, the GPS/LORAN can tell you the name and city, the runway headings and length, and the various communication channels, as well as the lat/lon. For VORs and NDBs, the receiver can tell you the city and state, its name, frequency, latitude, and longitude. The name of a VOR or NDB is not necessarily the same as its identifier. It will also display the latitude and longitude of an intersection. I will show you how to *recall any waypoint* from the database so that you can review the information on it.

1. There are two sets of knobs, each with a small inner and large outer knob. In general, the large outer knob is used to select the function or mode and the small inner knob is used to scroll through the data available in that function. You turn the large left knob to the category of the waypoint that you are interested in and turn the large right function knob to the INFO setting. **So lets say you want to know the lat/lon coordinates of the MILIS intersection.**
2. **Turn the large left knob to the INT setting with the large right knob on INFO.**
3. As you see, the receiver does not immediately show MILIS. To get to it you must turn the **small left knob to scroll through the alphabetically arranged waypoints in that category. Alternatively, you could get to it by the character entry method.**
4. **Press the CRSR button on the side of the display where the waypoint* identifier is displayed.** The cursor button will light up to indicate that it is in the editing mode. The first letter will begin to flash.

5. **Using the small left knob, change the flashing letter to the first letter of the waypoint you are interested in.** The characters are displayed in the following order by turning the knob from left to right from the beginning: a space, the letters of the alphabet, numbers 1 through 9 and some other characters such as slashes and number signs.
6. **Turn the large left knob to move the cursor over to the next space where you select the next letter by the same method. Continue this until the entire waypoint identifier is entered.** As you scroll through the letters, you will see the information for the waypoints in the database. If there is no information displayed, then there is no waypoint in the database with that identifier. Do not press the CRSR when no information is displayed because the GPS/LORAN will think you are trying to enter a new waypoint with that identifier. For example there is no waypoint for PMU APT but there is one for PMV APT.
7. **Press the CRSR button once again to leave the character entry mode. Turn the right inner knob to scroll through the information on that waypoint.** As we turn the knob, we can see the latitude coordinate for MILIS is 42.06.3 and the longitude coordinate is 71.18.7.

Demonstrate once again with an APT waypoint and then allow them to recall 2 waypoints. Scroll through the information on each, describe each page of information. Ask them to try both the scrolling and character entry methods of recalling the identifier, advise when to use scrolling.

There may be times when you do not know the waypoint identifier but you might know the common name for the waypoint or its city of location. I will show you how to *retrieve the waypoint even though you do not know the identifier.*

1. Turn to the category of the waypoint you are searching for, in this case APT, using the large left knob as you did before, with the right knob set on INFO. (It does not matter that the waypoint displayed is not the one you are searching for at this point).
2. Turn the small right knob to display either the name or the city, whichever you decide to search for. If you know the name of the airport but nothing else, turn to the page displaying the name of the airport that appeared on the screen when you turned to the APT category. Note: Make certain that you do not confuse the page displaying the city of location with the page indicating the name of the waypoint. The name of the waypoint is not the same thing as the identifier. The location page will appear first as you scroll the information knob from left to right

and it will have the abbreviation for the state on the right hand side of the display. The name page will appear next but it will not have the state abbreviation on the right.

3. Press the right CRSR button and enter the first four or five characters of the desired name or city.
4. When you find the desired waypoint, press CRSR again to turn the cursor off.

So lets say you know there is an airport in Fitchburg but you don't know the identifier and you want to have information on the airport.

1. Select the **APT** category. (*APT on left, INFO on right*)
2. Using the small right knob, turn to the location page for the airport that appears.
3. Press **CRSR** to enter the location. Spell out Fitchburg using the character entry method. You probably won't have to spell out the whole word because the GPS/LORAN fills in the rest of the word if it is in the database.
4. Once Fitchburg is on the display, Press **CRSR** to enter the location and then you can view any of the information on the waypoint as you did before, by turning the small right knob.

Often a city name will exist in several different states. Check the state code to the right. If it is not the one you are looking for, while in character entry mode, turn the small left knob to scroll the waypoints, checking the state code to the right until you see the one you're searching for. Waypoints will be cycling alphabetically according to identifier.

Demonstrate again, using a VOR located in Springfield MO. Allow them to recall two. Ask them to try both scrolling and character entry methods.

IV. How to Create a Flight Plan

A flight plan is a sequence of waypoints that define the route that the pilot plans to follow. The flight plan may consist simply of a starting waypoint and a destination waypoint, or there may be several waypoints in between. *show or draw a diagram* The pilot flies from the first waypoint to the second to the third and so on until he or she reaches the destination. A leg of the flight plan is a

course line from one waypoint to another. Using the GPS/LORAN you can store a sequence of up to twenty waypoints, or nineteen legs to form a flight plan.

1. Turn to the flight plan mode, FPL, with the large left knob. If there is no flight plan stored, there will be a string of question marks in the left half of the display. The right half of the display may show "Undefined Leg" in which case you turn the right outer knob until you see "Add Waypoint ACK?."
2. You will see the ACK button on the far right side begin to flash. The receiver does this to prompt the user, and you will see it quite often while using the receiver. Whenever the ACK button is flashing, the receiver is asking you if you would like to acknowledge, or carry out the action described on the display. You will have to press ACK to acknowledge the operation displayed. If the button flashes and there is no prompting question on the display such as "Add Waypoint ACK?", then the receiver is trying to advise you of a potentially dangerous condition or situation of which you should be aware. In that case you should press ACK to read the message and press ACK again to acknowledge that you understand the advisory. In this case it is prompting you with the question of whether or not you would like to add a waypoint to the flight plan. If you would, then press ACK, if not then turn the large left knob to get out of the FPL mode.
3. Press ACK and the receiver will prompt you for the waypoint you want to select.
4. Turn the right outer knob to the VOR category. Enter the identifier PSC by the same method we used before, either by scrolling through the list or by character entry. Note: as you are entering the identifier, the ACK button will flash only if you are displaying a waypoint that is in the database - it will not flash if there is no waypoint in that category of the database with that identifier. For example, it will flash if you enter PSC VOR but not for PSD because there is no waypoint in the VOR category of the database named PSD. If you accidentally press ACK when it is not flashing, the GPS/LORAN saves your present position as a waypoint. *demonstrate* Also, make sure that you are in the right category. If you are supposed to be entering a VOR waypoint and you are entering a waypoint in the INT category by accident, press the CRSR button. This will not enter the waypoint but it will allow you to change the category and enter it in again.
5. When you have PSC displayed as the desired waypoint, press the flashing ACK to enter it into the flight plan and you will be asked again if

you want to add a waypoint. **DELETE THIS WAYPOINT FOR THE SUBJECT NOW.**

Lets say we want to enter a flight plan and have JFK airport as our first waypoint in this flight plan.

1. Turn the right outer knob to APT and then bring up JFK.
2. Press the flashing ACK because it is the waypoint you want and it then prompts you to add another waypoint.
3. The experimenter will now help you to enter the rest of the flight plan. The waypoints and their respective categories are as follows:

waypoint	category
JFK	APT
ACY	VOR
NEL	NDB
CASVI	INT
FSD	APT

Show subject how to check the accuracy of the flight plan by scrolling the left inner knob (first get out and back into FPL mode).

V. How to Edit the Flight Plan

During the flight it may be necessary for the pilot to edit the flight plan by adding, deleting or changing waypoints. Also if you make a mistake while entering the flight plan you can correct it using the editing functions. For example if you misspell the identifier or press the ACK button too early you may accidentally enter a wrong waypoint into the plan. You can use the delete operation described below to correct the error. The *basic procedure for the editing operations* is as follows:

1. Set the large left knob to FPL.
2. Turn the small left knob to scroll to the leg of the flight plan that you want to edit. If you want to delete or change a waypoint, scroll the flight plan so that particular waypoint is the "To" waypoint. If you want to insert a waypoint, scroll the flight plan to display the two waypoints between which you want to insert the new waypoint.
3. Turn the large right knob to the editing function that you want.

4. Press the flashing ACK to carry out the edit.

First lets *change one waypoint to another*. Change the ACY VOR waypoint to be a new waypoint.

1. Set the left outer knob to FPL and scroll the flight plan (using the left inner knob) so "ACY" is the "to" waypoint.
2. Turn outer right knob to "Change ACY ACK."
3. Press ACK.
4. Using the knobs on the right, select the category and the specific waypoint to replace it, the Nanci intersection.
5. Press the flashing ACK to enter it.

After demonstrating this, allow them to change a waypoint.

Now we will delete CASVI INT:

1. With the left outer knob set on FPL, scroll the flight plan so **CASVI** is the "to" waypoint.
2. Turn the large right knob to the display message prompting you to delete a waypoint.
3. Press **ACK** to enter the delete. *Allow them to delete a waypoint.*

Now we will *insert* the DIXIE INT between the Nanci INT and the NEL NDB:

1. With the left outer knob set on FPL, scroll the flight plan to display the two waypoints, Nanci and NEL,. between which you want to insert the new waypoint, DIXIE.
2. Turn the right outer knob to "Insert wpt ACK?"
3. Press **ACK**.
4. Use the large right knob to select the category and the small right knob to scroll through the waypoints in the flight plan or use the character entry method to select the waypoint to insert.
5. Press the flashing **ACK** to enter it.

Allow them to insert a waypoint.

You will also notice there is a prompt "Add waypoint ACK?." This is acknowledged if you want to add a waypoint to the end of the flight plan, not to insert a waypoint between two others. The steps to add a waypoint in this editing mode are the same as when you were creating the flight plan.

If you have to insert some waypoints and delete others in the same segment of the flight plan it is easiest to use the "Change waypoint" function. For example, if you have to delete two waypoints and put in three new ones, the easiest way is to change the first two to new ones and insert the other new one rather than deleting the three old ones and inserting the new ones.

APPENDIX D
PROCEDURES

Day 0 Training

The business day before, call to remind the subject of your appointment. Be sure to determine for what test interval condition he/she will be available (7 or 14). Tell subject to bring corrective lenses if needed.

Prior to subject arrival:

1. Turn on simulator and other equipment, hang "DO NOT DISTURB" sign, mark video tapes.
2. Assign proper subject number (1-5), referring to conditions sheets.
Pilot # _____.
3. Insert a blank, labelled diskette into drive b. Initiate first flight trial conditions by typing **TUNEGPS1. SUBJ. DAY (@C:\IFT3213)**. Verify turbulence (1-3) and trial# and hit ENTER, press Y to continue. Press ESC to get rid of flight instrument window. Switch A/B box from experimenter's monitor to subject's monitor.
4. Make certain all experimental materials are available (hard copies and disk), including formatted diskettes for data files.

When subject arrives:

Administer visual acuity test in full illumination. Proceed upon successful completion. *(If they do not have 20/20 vision or close to it, stop here).*

Wear corrective lenses? Y N Worn today? Y N

1. Read informed consent form and have it signed. Give a charge number if applicable. Fill out information sheet for check remittance.
2. Administer pilot experience questionnaire.
3. Adjust subject's seating relative to controls. Position the bar behind the subject's chair.
4. Turn lights down (left off; right to black mark) and keep door closed for the remainder of the experiment.
5. "You will be asked to complete a series of 18 trials today. Some of these trials will involve programming the receiver (entering and editing a flight plan), some will involve flying the simulator, and others will combine both of these tasks.

We will begin by familiarizing you with the simulator and the operation of the receiver." (Order depends on subject number).

6. If flight sessions are first, familiarize subject with simulator and flight task using the simulator instructions and graphic presentation.
7. Read description of instruments while subject is viewing simulator monitor. Give subject handout describing instruments for review.

Flight Instruments On the display going clockwise from lower left corner:

Automatic Direction Finder (ADF)

Turn Coordinator

The single hash marks on the right and left side indicate that the aircraft is in a "standard rate" ($3^\circ/\text{second}$ or $360^\circ/\text{two minutes}$) turn. Displacement of the "ball" indicates an uncoordinated turn that can be corrected by applying rudder on the same side as the ball (i.e., step on the ball).

Airspeed Indicator

The speed of the aircraft is displayed as indicated airspeed (IAS) in knots (kts). The indicator has three colored bands and a red marker. The green band is the normal operational speed range, the white band is the stall speed range for full flaps, the yellow band is a caution range, and the red mark is the "never exceed" speed. Each trial will always begin at approximately 100 kts airspeed and will vary throughout a trial depending on aircraft attitude.

DO NOT ATTEMPT TO ADJUST AIRSPEED USING THE THROTTLE CONTROL.

Outside View Display

ADF Tuner lower left

Magnetic Compass/Marker Beacons upper left

Navigation Radio (NAV) Cluster right side

Tachometer

Fuel Cluster

Engine Instruments

Clock

Throttle Cluster

Elevator/Trim/Flap Position Indicators

(Do not attempt to adjust the trim and flaps during the experiment).

Gyro Compass/Directional Gyro

Provides more accurate heading information than the traditional magnetic compass. However, it is vulnerable to precession over time and cannot be

adjusted to compensate. Do not use this instrument for precise tracking information.

Attitude Indicator

Aircraft pitch and bank are shown with this instrument. The vertical hash marks are graduated in 5° increments for pitch. The bank index (outer circle) is graduated in 10° increments up to the first 30° of bank, and in 30° increments for up to 90° of bank. The blue portion of the indicator shows the direction of the sky and the gray portion indicates the earth relative to the aircraft attitude.

Altimeter

Shows aircraft altitude (above sea level) and is preset at 5000 feet for each trial. The barometric pressure is preset at 29.92 and does not require adjustment. **DO NOT ATTEMPT TO ADJUST THE ALTIMETER DURING THE EXPERIMENT.**

VOR1/VOR2

The number one VOR (V1) is operational and the course deviation needle (CDI needle) should be used for primary tracking information. The CDI needle will be displaced toward the left or right, depending upon aircraft heading, relative to the tuned-in course. **DO NOT ATTEMPT TO ADJUST THE VOR DURING THE EXPERIMENT TO COMPENSATE FOR COURSE DEVIATIONS, FLY THE AIRCRAFT TO MAINTAIN A CENTERED CDI NEEDLE.** The second VOR (V2) is INOPerative during the experiment.

Vertical Speed Indicator

Displays the rate of climb and descent in hundreds of feet per minute. This instrument will vary according to aircraft attitude.

Other:

Rudder pedals and yoke functional

Throttle - remind subjects not to use

No trim

Yoke - must be centered prior to each flight trial. Show subject how to line up yoke with black line and to use elevator instrument (tick mark between the R and I in TRIM).

"At the end of each flight, you will be presented with two scores you'll use to assess your own performance. The first score represents cross-track error score (XTK), which is computed as the average horizontal deviation away from the course line expressed in feet. Next you will find your altitude score, which is computed as the average vertical deviation expressed in feet. The better your

performance for either of these measures, the lower your scores will be. Please try to keep your scores as close to zero as possible."

8. Refer to conditions sheet to determine proper order for the following:
Some subjects fly, program, fly and program; other subjects program, fly, fly and program.

Flight Trials

(FLIGHT DURATION: 4 MINUTES)

Instruct subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Before each trial begins, please make sure the yoke is centered. To verify, use the black line on the yoke and the elevator position indicator. Do you have any questions? Ready?"

To initiate flight trials:

For trial 1, press pause (P) to start; for the remaining trials...

1. Verify turbulence level and trial number, press Y to continue.
2. Press ESC.
3. Switch A/B box from experimenter's monitor to subject's monitor.
4. Press pause (P) to start simulation.
5. Say "OK" while depressing (P) to indicate the end of each flight.
6. Press 9 twice and Y, ENTER.
7. Enter flight plan number for trial just completed.
8. Receive feedback from trial.
9. Switch A/B box to experimenter's screen after subject has viewed feedback.
10. Press Y to continue, begin next trial.

Programming Trials

Prepare the GPS/LORAN to run skttop simulation mode and give receiver operating instructions to the subject. Instruct the subject on how to operate the receiver verbally and with written instructions. Make sure to sit on the right side of the subject while reviewing receiver procedures.

Place first flight plan on knee board upside down. Instruct subject as follows:

"When you complete the flight plan, please check it for accuracy and verbally indicate when you are finished. Please erase the flight plan prior to the next trial."

Flight/Programming Trials

(FLIGHT DURATION: SUBJECT DEPENDENT)

Be sure that the GPS/LORAN is set to FPL mode and does not contain a flight plan. (????? should appear on lefthand side; "Undefined Leg" should appear on the right). Place first flight plan on the knee board face down and instruct the subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Remember that your attention should primarily be given to flying. Unlike a real aircraft, if you divert your attention from flying for extended periods you may experience difficulty in making control adjustments. I will say *begin* after 30 seconds of your flight have elapsed (USE STOPWATCH). At this point, please turn the flight plan right-side up and begin programming. When you have finished entering the flight plan, please check it for accuracy, making sure to fix any mistakes that you might have made, and press the PAUSE/PROFILE button on the control panel (INDICATE). You may erase the flight plan when the trial is completed. Before each trial begins, please make sure the yoke is centered. Do you have any questions? Ready?"

Initiate flight simulation.

******Mention that yoke or pedal movements made in between trials (when simulation is not displayed) can be disruptive to data collection procedures.******

9. Thank the subject for participating and remind him to return the next day for his first data collection session. Issue a reminder slip and record times on subject schedules. **Delete LASTRIC.PTH.** Backup (hard and floppy) and file data. Prepare summary of Subject's comments.

Day 1 Data Collection

One business day before, call to remind the subject of your appointment.

Prior to subject arrival:

1. Turn on simulator, prepare for first flight trial and hang "DO NOT DISTURB" sign.
2. Make certain that the GPS/LORAN is cleared of flight plans created during the latest session.
3. Set up camera and VCR. Mark video tape.

4. Make certain all experimental materials are available (hard copies and disk).

When subject arrives:

1. Worn corrective lenses today? Y N N/A
2. Adjust subject's seating relative to flight controls and answer any questions the subject might have regarding the simulator and flight task. Explain that you cannot answer receiver operation questions.
3. Turn lights down and close the door for the remainder of the experiment.
4. "You will be asked to complete a series of 18 trials today. Some of these trials will involve programming the receiver, some will involve flying the simulator, and others will combine both of these tasks."

Flight Trials

(FLIGHT DURATION: 4 MINUTES)

Instruct subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Before each trial begins, please make sure the yoke is centered."

Initiate flight simulation. Repeat procedure for remaining flights. Note that crashed trials should be repeated.

Programming Trials (remember to video record)

Be sure that the GPS/LORAN is set to FPL mode and does not contain a flight plan (????? should appear on lefthand side; "Undefined Leg" should appear on the right).

Place first flight plan on knee board upside down. Instruct subject as follows:

"When you complete the flight plan, please check it for accuracy, making sure to fix any mistakes that you might have made, and verbally indicate when you are finished. Please erase the flight plan prior to the next trial."

Flight/Programming Trials

Be sure that the GPS/LORAN is set to FPL mode and does not contain a flight plan. Place first flight plan on knee board and instruct the subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Remember that your attention should

primarily be given to flying. I will say *begin* after 30 seconds of your flight have elapsed (USE STOPWATCH). At this point, please turn the flight plan right-side up and begin programming. When you have finished entering the flight plan, please check it for accuracy, making sure to fix any mistakes that you might have made, and press the PAUSE/PROFILE button on the control panel (INDICATE). You may erase the flight plan when the trial is completed. Before each trial begins, please make sure the yoke is centered. Do you have any questions? Ready?"

Initiate flight simulation. Repeat for remaining flights, recording programming errors (video and manual) for each flight trial.

After each trial, ask the subject reasons for error commission (use the checklist). Record the point at which the subject starts programming during flight and the time the subject finishes the last control manipulation for each flight.

Note: Use the stopwatch for recording F trials (4 minutes). Use clock on video monitor to record time for P and FP trials.

_____	begin	_____	end	_____	Tot	Trial 1	F P FP
_____	begin	_____	end	_____	Tot	Trial 2	F P FP
_____	begin	_____	end	_____	Tot	Trial 3	F P FP
_____	begin	_____	end	_____	Tot	Trial 4	F P FP
_____	begin	_____	end	_____	Tot	Trial 5	F P FP
_____	begin	_____	end	_____	Tot	Trial 6	F P FP
_____	begin	_____	end	_____	Tot	Trial 7	F P FP
_____	begin	_____	end	_____	Tot	Trial 8	F P FP
_____	begin	_____	end	_____	Tot	Trial 9	F P FP
_____	begin	_____	end	_____	Tot	Trial 10	F P FP
_____	begin	_____	end	_____	Tot	Trial 11	F P FP
_____	begin	_____	end	_____	Tot	Trial 12	F P FP
_____	begin	_____	end	_____	Tot	Trial 13	F P FP
_____	begin	_____	end	_____	Tot	Trial 14	F P FP
_____	begin	_____	end	_____	Tot	Trial 15	F P FP
_____	begin	_____	end	_____	Tot	Trial 16	F P FP
_____	begin	_____	end	_____	Tot	Trial 17	F P FP
_____	begin	_____	end	_____	Tot	Trial 18	F P FP

Delete LASTRIC.PTH. Thank subject for participating and remind subject to return in either 7 or 14 days (check the proper condition). Issue a reminder slip and record times on subject schedules. File and download all data.

Day 7 or 14 Data Collection

One business day before, call to remind the subject of your appointment.

Prior to subject arrival:

1. Turn on simulator, prepare for first flight trial, and hang "DO NOT DISTURB" sign.
2. Make certain that the GPS/LORAN is cleared of flight plans created during the latest session.
3. Set up camera and VCR.
4. Make certain all experimental materials are available (hard copies and disk).

When subject arrives:

1. Worn corrective lenses today? Y N N/A
2. Adjust subject's seating relative to flight controls and answer any questions the subject may have regarding the simulator and flight task. Explain that you cannot answer receiver operation questions.
3. Turn lights down and close the door for the remainder of the experiment.
4. "You will be asked to complete a series of 14 trials today. Some of these trials will involve flying the simulator, and others will combine flying and the receiver programming task."

Flight Trials

(FLIGHT DURATION: 4 MINUTES)

Instruct subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Before each trial begins, please make sure the yoke is centered."

Initiate flight simulation. Use stopwatch to monitor 30 second mark and tell subject to begin. Repeat procedure for remaining flights. Note that crashed trials should be repeated.

Flight/Programming Trials

Be sure that the GPS/LORAN is set to FPL mode and does not contain a flight plan. Place first flight plan on knee board and instruct the subject as follows:

"Please maintain your altitude at ± 100 feet and use the CDI to maintain your course as accurately as possible. Remember that your attention should primarily be given to flying. I will say *begin* after 30 seconds of your flight have elapsed (USE STOPWATCH). At this point, please turn the flight plan right-side up and begin programming. When you have finished entering the flight plan, please check it for accuracy, making sure to fix any mistakes that you might have made, and press the PAUSE/PROFILE button on the control panel (INDICATE). You may erase the flight plan when the trial is completed. Before each trial begins, please make sure the yoke is centered. Any questions? Ready?"

Initiate flight simulation. Repeat for remaining flights, recording programming errors (video and manual) for each flight trial.

After each trial, ask the subject reasons for error commission (use the checklist). Record the point at which the subject starts programming during flight and the time the subject finishes the last control manipulation for each flight. Continually monitor subject's programming manipulations and check against flight plans.

Note: Use stopwatch for recording F trials (4 minutes). Use clock on video monitor to record time for P and FP trials.

_____	begin	_____	end	_____	Tot	Trial 1	F P FP
_____	begin	_____	end	_____	Tot	Trial 2	F P FP
_____	begin	_____	end	_____	Tot	Trial 3	F P FP
_____	begin	_____	end	_____	Tot	Trial 4	F P FP
_____	begin	_____	end	_____	Tot	Trial 5	F P FP
_____	begin	_____	end	_____	Tot	Trial 6	F P FP
_____	begin	_____	end	_____	Tot	Trial 7	F P FP
_____	begin	_____	end	_____	Tot	Trial 8	F P FP
_____	begin	_____	end	_____	Tot	Trial 9	F P FP
_____	begin	_____	end	_____	Tot	Trial 10	F P FP
_____	begin	_____	end	_____	Tot	Trial 11	F P FP
_____	begin	_____	end	_____	Tot	Trial 12	F P FP
_____	begin	_____	end	_____	Tot	Trial 13	F P FP
_____	begin	_____	end	_____	Tot	Trial 14	F P FP

5. Administer post-experiment questionnaire.
6. Thank subject for participating.
7. **Delete LASTRIC.PTH**
8. Backup and file all data and manually record errors.

APPENDIX E
INFORMED CONSENT FORM

INFORMED CONSENT FORM

You have been asked to participate in the Receiver Programming Performance Study conducted by the Operator Performance and Safety Analysis Division of the Volpe Center.

The purposes of this study are to determine how long a person retains the knowledge required to operate a GPS/LORAN receiver, to identify the GPS/LORAN operations that are most prone to error, and to identify the types of errors that are made while performing GPS/LORAN operations. If you agree to participate, you will be asked to complete a brief questionnaire regarding your flight experience and any previous experience you may have had with using GPS/LORAN systems. You will then be familiarized with a flight simulator and trained to operate the receiver. Additionally, you will be asked to perform various programming functions using the GPS/LORAN system during flight simulation.

The experiment will take up to 10 hours to complete over a period of three days. There are no risks involved in participating in this study. Please do not hesitate to ask questions about the study at any time. Your data will be kept strictly confidential and your name will not be associated with your data.

Your participation in this study is strictly voluntary. If you agree to participate, you will either be given a Volpe Center account number to which you may charge your time, or you will be paid \$100.00. You are free to withdraw at any time without penalty. Your cooperation is sincerely appreciated.

Vicki Shearer and Ed Madigan
Researchers
Battelle Memorial Institute
Volpe National Transportation Systems Center
(617) 494-2464 and (614) 424-3325

Signature and Age of Participant

Date

Name (please print)

Address and Phone Number

Signature of researcher

Date

APPENDIX F

PILOT EXPERIENCE QUESTIONNAIRE

Pilot Experience Questionnaire

1. Age: _____
2. Gender: Male Female
3. Please estimate your flight times as accurately as you can:
total flight time _____ hours
total IFR flight time _____ hours
4. Please indicate the type of aviation experience you have. Check all that apply.
Part 121 _____ General Aviation _____
Part 135 _____ Corporate _____
Military _____
Please list the type(s) of aircraft currently flown:

5. Have you ever used a GPS/LORAN receiver prior to this evaluation?

YES NO

IF YES, please answer the remaining questions.
6. Please list all receivers you currently use: _____

Other receivers used: _____

7. Please estimate the percentage of time you use your receiver during flights:
_____ %

8. Does operating the GPS/LORAN receiver distract you from your primary flying tasks?

YES NO

If YES, how?

9. Would you recommend any design changes? YES NO If YES, please explain.

Knobs/Keys:

Labeling:

Displays:

Procedures:

For the receiver you use the most (please specify _____), answer the following:

10. Using the scale below, please rate the level of ease/difficulty associated with performing each of the following functions.

Functions	VERY EASY			NEUTRAL			VERY DIFFICULT	
	1	2	3	4	5	6	7	
Reading the display panel	1	2	3	4	5	6	7	
Creating a flight plan	1	2	3	4	5	6	7	
Changing a flight plan	1	2	3	4	5	6	7	
Overall usability	1	2	3	4	5	6	7	
Recovery from errors	1	2	3	4	5	6	7	
Operating the control	1	2	3	4	5	6	7	

APPENDIX G
POST-EXPERIMENT QUESTIONNAIRE

Post-Experiment Questionnaire

1. After using the GPS/LORAN receiver, which of the programming procedures were most confusing to you? (*i.e., recalling waypoints, creating flight plans, editing flight plans*) Why?

2. In your opinion, what is the single best feature of the GPS/LORAN? Why?

3. In your opinion, what is the single worst feature of the GPS/LORAN? Why?

4. Did you have any difficulties with retrieving information?

YES NO

If yes, please explain.

5. Did you find that the receiver programming logic corresponds with the way you think about following a flight plan?

YES NO

6. If you use GPS/LORAN when you fly, do you usually follow a flight plan or fly waypoint to waypoint? Please circle one response.

a. Not applicable -I do not use GPS/LORAN when I fly

b. I follow a flight plan

c. I fly waypoint to waypoint

7. What types of navigation information would you prefer to see displayed on the GPS/LORAN monitor at all times? Please rank your choices in order of importance and provide an explanation.

8. Would you recommend any design changes to the receiver you used for this experiment?

YES NO If YES, please explain.

Knobs/Keys:

Labeling:

Displays:

Procedures:

APPENDIX H
POST-EXPERIMENT QUESTIONNAIRE RESPONSES

POST-EXPERIMENT QUESTIONNAIRE RESPONSES

Responses are given in bold, the response frequency is given to the left.

1. After using the GPS/LORAN receiver, which of the programming procedures were most confusing to you? (*i.e., recalling waypoints, creating flight plans, editing flight plans*) Why?

(1) The procedures themselves were explained well, however the L.E.D. display could be laid out better.

(1) Editing. Seemed to be easier to misidentify the type of waypoint.

(3) No confusion

2. In your opinion, what is the single best feature of the GPS/LORAN? Why?

(1) "Direct To." Very useable enroute. Position Accuracy.

(1) Being able to fly direct to any point at all including intersections and airports.

(1) Direct navigation; faster.

(1) Bright display.

(1) Nothing in particular stood out.

3. In your opinion, what is the single worst feature of the GPS/LORAN? Why?

(1) Nothing in particular stood out.

(1) In the operation instructions, use of both inner and outer and large and small to describe knobs. Preferred large and small.

(1) Nav. error; i.e. poor triangulation, especially in precip.

(1) Although I have not experienced it, I've heard that reception can sometimes be disrupted especially when needed most; In hard IFR with heavy rain or snow.

(1) Time to scan a waypoint.

4. Did you have any difficulties with retrieving information? If yes, please explain.
- (3) NO
 - (1) YES; Display needs to be larger and better spaced for easier identification.
 - (1) YES; Several waypoints, as given, were not in database. I had to substitute something "on the fly."
5. Did you find that the receiver programming logic corresponds with the way you think about following a flight plan?
- (4) YES
 - (1) No way to answer Y or N based on this experiment, since there is no requirement to actually follow GPS/LORAN course guidance.
6. If you use GPS/LORAN when you fly, do you usually follow a flight plan or fly waypoint to waypoint? Please circle one response.
- (2) a. Not applicable -I do not use GPS/LORAN when I fly
 - (1) b. I follow a flight plan
 - (2) c. I fly waypoint to waypoint
7. What types of navigation information would you prefer to see displayed on the GPS/LORAN monitor at all times? Please rank your choices in order of importance and provide an explanation.
- (1) If I were using one, I would like: 1) Course to fly, 2) Course deviation, 3) Distance to waypoint, 4) Time to waypoint
 - (1) 1) Waypoint I am flying direct to as directed by CDI, 2) Distance to the waypoint I am flying to with approx eta according to current ground speed
 - (1) 1) Good waypoint alert info., 2) Time to fix (minimize fix overrun)
 - (1) 1) That it is working, 2) Crosstrack error in digital form i.e. tenths of a mile and which direction to correct, 3) Waypoint name, 4) Distance/Time to waypoint
 - (1) 1) Speed, 2) Waypt. to which I'm navigating, 3) X-track error in terms of CDI

8. Would you recommend any design changes to the receiver you used for this experiment? If YES, please explain.

(2) YES

(3) NO

Knobs/Keys:

(1) Make keys slightly larger and beep when pressed

(1) Should be able to slow to a letter, i.e, faster you turn, the more letters are skipped

Labeling:

(1) Poor; only selected item is lit. Very hard to see in dim light of test room

(1) Slightly larger

Displays:

(1) Dots tend to smear--maybe due to my aging eyes. Would prefer LCD segments or gas discharge

(1) Slightly larger and space between 5 letter ID and the word ACK

Procedures:

(1) ok

APPENDIX I
GENERAL COMMENTS

GENERAL COMMENTS

(T refers to training session, 1 refers to Test Day 1, 2 refers to Test Day 2)

GPS/LORAN COMMENTS

<u>Day</u>	<u>Comment</u>
T	Display could be larger - <i>it's</i> ok sitting still but in turbulence a bust! Numbers too small unless right in front of you...
T	Buttons too small for fingers and too hard to press...
T	Confusing which functions to perform on which side (primary v. secondary display)...that's why I never liked this unit
T	There are many ways to perform the same function correctly can get confusing to remember an exact procedure
T	Scrolling appears to work differently on the primary side than on the secondary side (must first hit cursor on secondary side)
1	The waypoint CDI#1 is confusing since only 3 letters for an NDB is expected
1	Add space between ACK? and Waypoint identifier...confusing at times
1	The waypoint CDI#1 confusing, has 1 character more than usual

SIMULATOR/APPARATUS COMMENTS

<u>Day</u>	<u>Comment</u>
T	Feels like it's flying an engine out
T	Feels like the yoke is off - won't go straight
T	Simulation is sensitive and pitch is strange
T	Tendency to turn left as if a heavy left wing
T	Roll unstable at this point or I'm not very adept (high turbulence condition)

GENERAL COMMENTS

SIMULATOR/APPARATUS COMMENTS (continued)

<u>Day</u>	<u>Comment</u>
T	The angle of the GPS/LORAN is disturbing (physical fatigue)
T	The simulation is somewhat unresponsive
1	Today the simulation feels closer to full-scale real
1	Some shoulder discomfort due to position of GPS/LORAN receiver
1	Responding (simulator) slow, feels like runaway trim in a plane...constantly fighting to hold it straight...
2	Harder to keep nose straight and level - acts like severe turbulence at times...

EXPERIMENTAL TASK COMMENTS

<u>Day</u>	<u>Comment</u>
T	Simulation does not respond like a real aircraft... Unable to make 1 brisk control input to correct course when attention is turned back to flying (from programming), Required strategy is to program in a series of sub-tasks rather than in one large chunk
T	It is difficult to program and fly, the task is demanding and it is hard to split attention
T	I'm concerned how to fly and program together, usually I turn on the autopilot
T	Have to know procedures down pat - no time to hover and think - just do
2	For NDB's and INT's I use CRSR entry, for other categories I scroll for the correct waypoint (because there are fewer waypoints in the other categories)