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Cockpit Integration of GPS: Initial Assessment—Menu Formats and Procedures

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16. Abstract

A popular portable Global Positioning System (GPS) unit (Megellan EC-10X), representative of this class of devices, was examined for its usability by general aviation pilots. Nine private pilots participated in the experimentation, which was accomplished in three phases: familiarization and training, usability testing, and post-experiment debriefing. During familiarization and training, participants were asked to study flow diagrams representing GPS interface logic, observed a demonstration of the unit's features and procedures, and then were allowed to practice with the unit until they could demonstrate proficiency. During the usability testing phase, participants performed 37 GPS-related tasks requiring waypoint setting, GPS navigation, and general GPS-data entry and retrieval. Findings from videotape, questionnaire, and debriefing data indicated that a number of menu structures interfered with the pilots' successful entry of data, editing of stored data, and activation of functions. For example, one source of confusion resulting in excess button presses was the need to deactivate the flight plan before any editing could be done. Recommendations are made for defining the form of the interface structure in this class of devices, including: A given function should be consistently assigned to one button, feedback should be consistent and meaningful, and an "undo" or "back" function would be a very useful way to decrease the number of button presses required by this interface.

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FOREWORD

A series of studies is being conducted as part of the Civil Aeromedical Institute's (CAMI's) General Aviation Human Factors Research program, which incorporates both near-term and far-term objectives. The program focuses on the integration of instrumentation into the general aviation cockpit. Because many companies are designing and developing general aviation in-cockpit devices, there is an increasing need to determine the degree to which sound human factors principles are being incorporated. The program involves the use of systematic usability testing procedures at the Institute's Usability Testing Laboratory to aid in identifying areas of design that may either hinder or enhance pilot performance and flight safety. The objective of this program is to generate comprehensive guidelines for the design and implementation of displays for current and future generation general aviation aircraft.

The Flight Standards Service (AFS-1) sponsored the study; the General Aviation & Commercial Division (AFS-800) provided project oversight. Dr. Thomas McCloy and Mr. Ronald Simmons, Human Factors Division (AAR-100), provided program coordination.

COCKPIT INTEGRATION OF GPS: INITIAL ASSESSMENT — MENU FORMATS AND PROCEDURES

INTRODUCTION

Justification for Current Testing

There has been a dramatic increase in the use of the global positioning system (GPS) by general aviation pilots that has led to a plethora of manufacturers producing GPS receivers. Unfortunately, there is no standard for data entry and retrieval, display type, or placement within the cockpit. General aviation pilots often use hand-held or add-on GPS units because they are relatively inexpensive and can be placed within the cockpit where space is available. While the use of GPS is a significant aid to navigation, it may distract the pilot from the primary tasks of flying and visual scanning. This is especially true when the receivers are not integrated into the instrument panel and do not utilize optimal software interface design. For instance, a poorly designed GPS menu structure may be such that it unnecessarily complicates the navigation task.

It should be noted that the potential problems seen with GPS units relative to the pilot-computer interface are not unique to these devices. This is merely the latest round of design efforts attempting to incorporate new technologies into the cockpit, with the usual difficulties associated with rapidly bringing a product to market. Many of the "smaller" companies (as compared with the large airframe manufacturers) involved in the production of these devices do not have any in-house human factors support, and much of the resulting design derives from engineering and marketing concerns, not necessarily human performance concerns. Thus, we see the same kinds of problems with these devices as have been seen in previous installations of computer-based cockpit aids to navigation. In particular, the familiar problem areas are once again the physical (hardware) and logical (software) interfaces between the pilot and the system. The research represented in this study was an initial effort to examine a typical (representative) portable GPS device and to determine what types of problems might be associated with its operation and, hence, might reduce its usability to the pilot.

Research addressing the human factors aspects of GPS controls, displays, and user attitudes was carried out by Nendick and St. George (1995). Data from 172 questionnaires filled out by New Zealand pilots who had utilized GPS were used in the analyses. It was found that errors included "transposing coordinates; transcription errors from maps when entering data into the GPS; hitting the wrong key; forgetting the keying sequence to obtain the correct information; and inadvertently pressing a key twice in turbulence, resulting in a change of mode or number or letter." Twenty percent of the questionnaires analyzed by Nendick and St. George reported misreading of displayed information.

Because all of the information needed by a pilot for GPS navigation cannot fit into the display window at once, the information is separated into various categories. Each category may be several pages deep. Ideally, the information needed most often should be on a single page, with the secondary information on adjoining pages. However, individual manufacturers have their own ideas about which items should go together (AOPA Air Safety Foundation, 1995). Miller (1981) employed an on-screen, word-search task for a depth/breadth tradeoff study and found that a two-level depth with eight-choice breadth at each level produced the fastest acquisition times and the fewest errors (compared with six-level depth/two-choice breadth, three-level depth/four-choice breadth, and one-level depth/sixty-four-choice breadth). An increase in depth and breadth increased acquisition time. However, Miller suggests that an expansion in breadth is preferred over an expansion in depth. Landauer and Nachbar (1985) came up with a similar conclusion when employing touch screens. The optimization of depth and breadth is an important design consideration for tasks requiring speed and accuracy. Miller (1981) concluded that, for systems of moderate size, the number of hierarchical levels should be minimized but not at the expense of display crowding.

Sometimes technical constraints will lead to a less than optimal interface design. Many systems are well organized in a technical sense, and focus on features and functions, rather than the overall purpose of the device and interface. The organization of a system should be designed with a thorough analysis and understanding of the primary tasks of the intended users (Mayhew, 1992).

Questions related to the usability of computer-based menu structures have been examined for some time now. However, these studies have, for the most part, focused on personal computer (PC) use. Though some GPS menu systems are similar to those seen on desk-top or lap-top computers, there are factors that make them unique. For instance, GPS display windows are generally smaller than computer monitors. Also, general aviation GPS users usually fly an aircraft while interacting with a GPS unit. Therefore, data were collected concerning the usability of a GPS unit while in simulated flight.

METHOD

The main purpose of the current study was to collect usability data from volunteer pilot participants as they interacted with a GPS unit during a flight in an aircraft simulator. Prior to data collection, a human factors evaluation of the GPS unit was carried out addressing control configuration, control labeling, display labeling, and menu structure. The results of this evaluation were examined, along with corresponding subsequent usability data.

Subjects

Nine volunteers were recruited from the local general-aviation pilot community. Each subject was fully informed of pertinent details of the study. All subjects were current private pilots. Subjects were screened through the use of a questionnaire to determine flight experience, GPS-use experience, and personal-computer experience, as well as other general questions relevant to the study. Novice GPS users were employed as test subjects to protect against negative transfer of training from previous use and familiarization with another GPS unit of different design.

Apparatus

Basic General Aviation Research Simulator (BGARS). The BGARS is a medium-fidelity, fixed-base, computer-controlled flight simulator (see Beringer, 1996). The controls and displays used in the BGARS simulate those of a Beech Sundowner. Control inputs are provided by analog controls, including a damped and self-centering yoke, navigation radio frequency selection module, rudder pedals, throttle, flap control, and trim control. Instruments are displayed on a cathode ray tube (CRT) and react in real time to all control inputs and aircraft conditions. The external views consist of a 50-degree forward-projected view and two smaller left-view CRTs.

GPS device. The GPS device evaluated in this study was the Magellan EC-10X, an off-the-shelf unit with a moving map display. This unit can be fastened to a pilot's upper leg with an elastic strap or mounted to the yoke. For this study, upper-leg placement was used because it represents the worst visual angle. The LCD display dimensions are 6.0" vertically, by 4.5" horizontally, and can be backlit with varying degrees of intensity. The Magellan has 12 buttons, which access and control the various features of the unit (see Figure 1). Some buttons are multi-functional, allowing the user to perform different tasks using the same button depending on which mode is operational. See Table 1 for a list of button functions. The GPS unit was interfaced with and driven by the BGARS software. The menu structure is graphically depicted in a flow-chart format in Appendix A.

Video recording equipment. Two color video cameras were positioned in and around BGARS to record subjects' hand and eye movements. The two video signals were converted to a single composite video image (split screen). The composite image was time stamped and recorded on videotape for subsequent examination. A high-resolution color monitor, located at an experimenter's station, was used for viewing the time-stamped composite video in real time and for review of the videotapes. Two microphones were used to pick up verbal instructions from the experimenter's station, as well as utterances from the subject in the flight simulator. The audio signals from both microphones were fed directly to the video recorder. See Appendix B for the audio/video equipment setup.

Event Timer/Recorder. A PC-based timing program was developed to capture task completion time as the usability test was being conducted. After the experimenter read a task instruction to a subject, the experimenter activated a computer timer with a key press. Upon task completion by the subject, the experimenter manually stopped the timer with another key press. Task start time, completion time, and elapsed time were written to the computer hard drive.

Event Marker. An event marker was developed to be used in conjunction with the event timer. With this device the experimenter had the ability to visually mark task-start times and task-completion times on videotape. The event-marker signal was emitted from

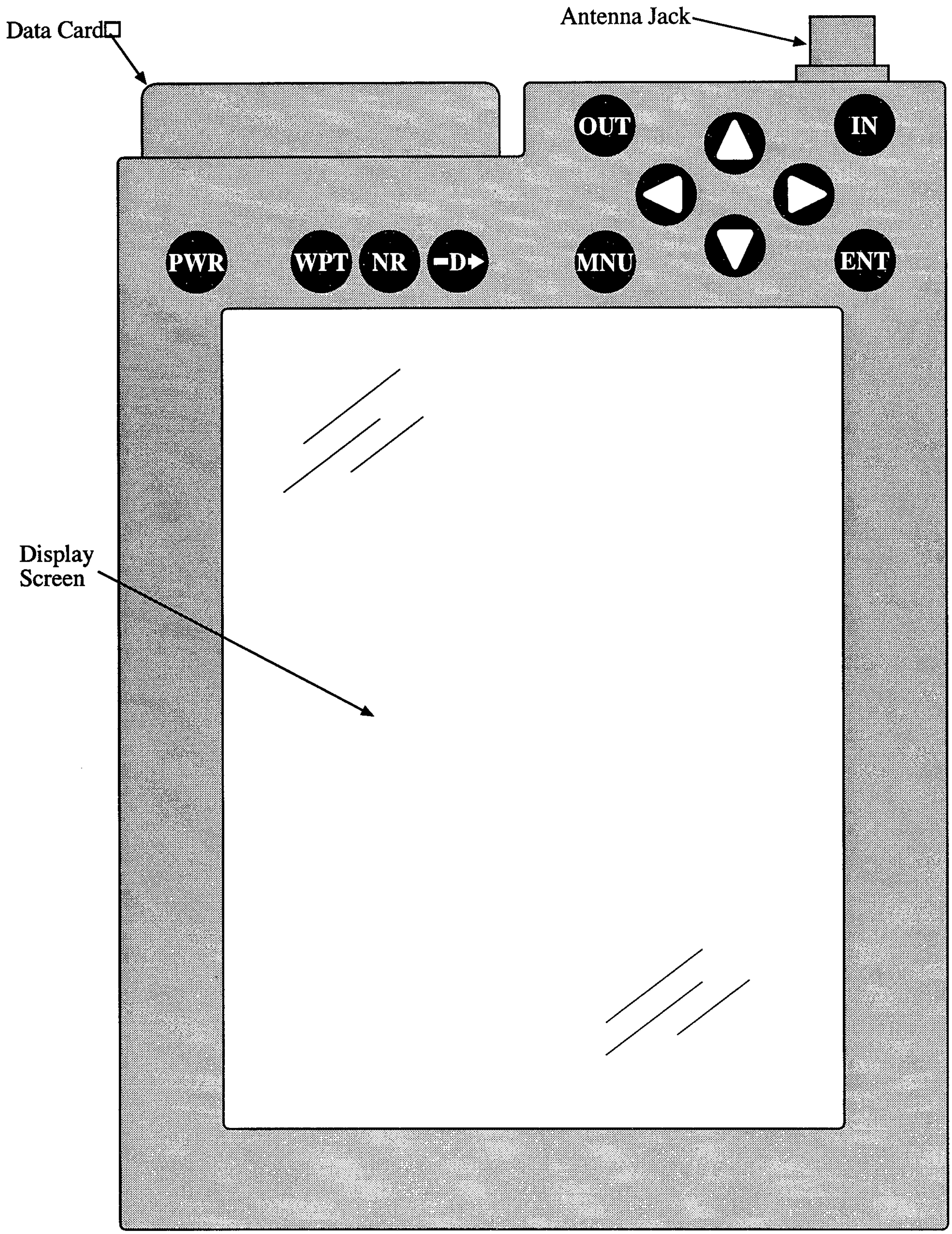

Figure 1. GPS Unit Button Configuration and Labeling (not to scale).

Table 1. GPS Unit Buttons and Associated Functions

PWR	• Turns POWER On / Off.
WPT	• Brings up the WAYPOINT menu in the Moving Map display.
NR	• Brings up the NEAREST menu from Moving Map, Navigation, and Location screens. • Cannot be accessed from Calculator, Flight Plan, Database and Setup Menu screens, any or their sub-options, or while in the Waypoint menu.
-D▶	• Plots a DIRECT course to selected navaid or destination while in the Moving Map and Database screens. • Cannot be accessed from any other location.
MNU	• Toggles between Main Menu and Setup Menu while in either respective location. • Used to escape/exit current menu location and backtrack to a higher level menu.
ENT	• Locks in selection (ENTER). • Activates option. • ***Switches to next flight plan while changing flight plans in Waypoint menu.*** • **Removes (takes OUT) user defined waypoints in the Database.** • **<u>"Flips" through information pages when in Moving Map display.</u>** • Activates flight plan while in the Flight Plan screen when cursor is located on a waypoint. (undocumented function). • Toggles between "Position" and "Cursor" modes in the Moving Map display.
IN	• Zooms IN while in Moving Map display. • Zooms IN while in user waypoint viewing screen of Database. • Inserts waypoints in Flight Plan screen.
OUT	• Zooms OUT while in Moving Map display. • Zooms OUT while in user waypoint viewing screen of Database. • **Removes (takes OUT) waypoints in Flight Plan screen.**
▲	• Moving Map cursor position UP. • Moves UP to previous menu option. • **<u>"Flips" to next information page when in Database.</u>** • Scrolls UP through alphabet when inputting alphanumeric text.
▼	• Moving Map cursor position DOWN. • Moves DOWN to next menu option. • **<u>"Flips" to previous information page while in the Database.</u>** • Scrolls DOWN through alphabet when inputting alphanumeric text.
◀	• Moving Map cursor position LEFT. • Move to character position to the LEFT when inputting alphanumeric text. • ***Switches to previous flight plan while in Flight Plan screen.***
▶	• Moving Map cursor position RIGHT. • Moves to character position to the RIGHT when inputting alphanumeric text. • Switches to next flight plan while in Flight Plan screen.

(Note: Variations in fonts will be referred to in the Results section of this paper. [Also take special note of the bold, bold-underlined, and bold-italic lines, which emphasize some of the inconsistencies in function allocation.])

a light source placed directly in front of one of the camera lenses. The light source, an infrared bulb, was not visible to the subjects.

Questionnaires. The participants in this study completed a pre-flight participant experience questionnaire and a post-flight ease-of-use questionnaire. The pre-flight questionnaire consisted of basic questions pertaining to age, gender, flying experience, GPS experience, and personal computer experience.

The post-flight questionnaire consisted of various open-ended, free-response questions and horizontally-oriented descriptive graphic rating scales with anchors of "strongly disagree," "neither disagree or agree," and "strongly agree." Participants were instructed to place a single vertical line on several scales to indicate the level of agreement with each corresponding statement. Each question pertained to the use of the GPS unit.

Procedure

There were three main phases in this study. In Phase 1, each subject completed a pre-test screening questionnaire and was trained to use the GPS unit and BGARS. The functions of the GPS controls were first demonstrated by the experimenter as the subject observed. Following the brief overview, a flow diagram of the GPS menu structure was used to graphically highlight the GPS features and organization of the menu system. Following the overview of controls, features, and menu structure, the experimenter demonstrated menu and control functions while using the GPS unit. The subject was then allowed to interact with the GPS unit and "explore" the system. Each subject was given a sheet containing various tasks to accomplish while using the GPS unit. Subjects were instructed to question the experimenter if confused about any aspect pertaining to the use of the GPS unit. Once the subjects felt comfortable using the GPS unit, the experimenter tested their knowledge of the unit by asking them to perform tasks similar to those that would be in the forthcoming usability test. The participants were tested until they could demonstrate proficiency by accomplishing all tasks given to them by the experimenter. The subjects were then familiarized with the BGARS controls and displays and allowed to fly a short course to become acquainted with the flight characteristics of the simulator. This training and familiarization phase involved approximately three hours of participation.

In Phase 2, the GPS-usability test took place. Subjects accomplished routine flight tasks in the BGARS and performed 37 GPS-related tasks requiring waypoint setting, GPS navigation, and general GPS data entry and GPS data retrieval (see Table 2). Each GPS-related task was given verbally by the experimenter (located at the experimenter station) to the subject in BGARS, through an aviation headset. A second experimenter sat slightly behind and to the side of the subject in BGARS to observe and take notes. This testing phase involved approximately one hour of flying and interacting with the GPS unit.

Phase 3 was the post-flight debriefing. Following the flight, the participants completed a post-flight questionnaire and were debriefed by the experimenter. During the debriefing session, both experimenters asked questions of the subjects concerning apparent problems the subjects had experienced when interacting with the GPS interface and responses on the post-flight questionnaire. The debriefing was kept rather informal so that the subjects felt comfortable offering information and responding readily to open-ended questions from the experimenters.

RESULTS

The collected data were in written and videotape form to be used for subsequent analyses. This section is organized so that it will be clear *where* subjects made errors when interacting with the GPS interface and why they made those errors.

A-Priori Human Factors Evaluation: Physical Layout of the GPS Unit

An evaluation of the GPS hardware and software configuration was carried out prior to the usability study. The purpose of this evaluation was to determine if any of the characteristics of the GPS unit would inhibit the system's efficiency-of-use. If hardware interface problems were discovered before subjects were run, it would indicate that subsequent usability test findings may be caused, in part, by these problems.

The push buttons on the GPS unit were found to be adequate. Diameter, displacement, and center-to-center spacing were appropriate. The push-button labels were located on the buttons and contrasted with the equipment background. The push-button labeling was backlit so that it was easily discernible in darkness.

Table 2. Instructions Given to Subjects Doing Usability Testing

1. In the flight plan screen set a waypoint at Wichita Mid-Continent
2. Set a second waypoint at Newton City Airport, identified KEWK.
3. Activate the flight plan.
4. In the moving map display, determine the tower frequency of the airport you are presently at, KICT, and read it back to me.
5. In the Calculator menu, input the information necessary to calculate wind speed and direction.
6. Access the Flight Plan screen.
7. Delete only the second waypoint which is the Newton City Airport, identified KEWK
8. Add a waypoint in its place at the STONS intersection.
9. Add a third waypoint at the Shroeder Field Airport, identified as M66.
10. Set the flight plan up to fly and go to the moving map display.
11. In the waypoint menu in the moving map display, change the flight plan by deleting the STONS leg, then return to flight.
12. In the waypoint menu, alter the flight plan by adding a waypoint at McPherson City.
13. Place a second waypoint near the airport 47K.
14. Place a third waypoint at Sedgwick.
15. Set the unit up to fly and return to the moving map display.
16. in the waypoint menu, alter the flight plan by adding a leg from the M66 waypoint to the McPherson City waypoint.
17. Place a second leg from the McPherson City waypoint to the waypoint near 47K
18. Place a third leg from the waypoint near the airport 47K to the Sedgwick City waypoint.
19. Set the unit up to fly and return to the moving map display.
20. In the Flight Plan screen, alter the flight plan by removing only WPT001.
21. Set the unit up to fly and return to the moving map display.
22. In the waypoint menu, delete the waypoint located at McPherson City.
23. In the waypoint menu, switch to flight plan ten, set it up to fly, and return to the moving map display.
24. Switch back to flight plan one, set it up to fly, and return to the moving map display.
25. In the Calculator menu, input the information necessary to calculate fuel consumption.
26. Report the fuel consumption for the KICT to M66 leg.
27. Alter the flight plan by adding the Newton City Airport, KEWK, to the end of the itinerary and set it up to fly.
28. Alter the flight plan in the waypoint menu to delete the Sedgwick City waypoint, set it up to fly, and return to the moving map display.
29. Access the airport information screen of the Database.
30. Find the Wichita Mid-Continent Airport, located in Wichita, identified KICT.
31. Report the field elevation, and the length and width of Runway 01L.
32. Create a direct course to the third nearest airport.
33. Place the cursor on Newton City Airport, identified KEWK, and create a direct course.
34. Use the Flight Plan screen and clear out flight plan one.
35. Use the Database to delete all the user defined waypoints.
36. Clear the flight track.
37. Return to the moving map display.

Control labeling did not appear to be intuitive in all cases. For example, pressing the button labeled MNU did not take the user specifically to a menu but generally to a higher level of the menu structure or "out" of a certain mode. See Huntley, et al. (1995) for a comprehensive human factors and operations checklist for standalone GPS receivers.

Button Presses to Accomplish GPS Tasks

One clear indication of the work required to accomplish a given task when using an interface is the number of keystrokes/button presses necessary for task completion. In Figure 2 a graph with the minimum number of button presses needed for the completion of each of 36 GPS-related tasks, and the average excess button presses executed by subjects to accomplish a given GPS-related task is shown (task 26 was excluded because no button presses were needed for this task). An important finding is that the total number of button presses per task is significantly correlated with the average head-down time per task ($r = 0.8163$; $p<.01$).

Excess button presses are often a function of the method by which subjects chose to enter alphanumeric information. For example, when a subject selected an alphanumeric string to be altered, the cursor would default on the right-most character. Some subjects chose to move the cursor to the left-most character before entering the necessary information. This action is thought to be a natural tendency that results from reading left to right. Subjects were also observed moving the cursor through more menu selections than necessary to reach their desired selection. For example, when the cursor was located at the top of a list in a menu, some subjects were observed moving the cursor from top to bottom through the list. However, the cursor could have been moved "up" from the top of the menu, and the cursor would have appeared at the bottom of the menu.

Excess button presses were caused, in large part, by subject confusion concerning the function of the OUT button and the ENT button and also because a flight plan had to be deactivated before it could be altered (Tasks 7 and 20). A flight plan was usually deactivated by subjects prior to any attempt to alter it. However, following the deactivation of the flight plan, some subjects would unknowingly reactivate the flight plan by erroneously pressing the ENT button (instead of the OUT button to "take out" a waypoint). Because the reactivation of the flight plan was not an obvious result of pressing the ENT button, most subjects did not notice that the flight plan had been reactivated. Therefore, subjects simply assumed that pressing the ENT button was an incorrect action and pressed the OUT button (the correct action initially). However, previously pressing the ENT button had reactivated the flight plan, thus no result occurred when the OUT button was pressed. Some subjects then pressed the ENT button again. The experimenters referred to this type of erroneous action as a "double error" because subjects were pressing an incorrect button while the flight plan was still activated.

Some subjects initially pressed the OUT button but did not deactivate the flight plan; therefore, no result occurred from pressing the OUT button. Several subjects then deactivated the flight plan and completed the task. However, other subjects assumed that pressing the OUT button was an incorrect action and pressed the ENT button (double error). Pressing the ENT button did not accomplish the task either, therefore the subjects were confused as to which button would remove a waypoint. These subjects eventually deactivated the flight plan, but occasionally pressed the ENT button again, thereby reactivating it. Most subjects did not notice the result of their action because the reactivation of the flight plan was not an obvious result of pressing the ENT button. As can be seen, the double-error event caused confusion and slowed the performance of a relatively simple task.

Excess button presses were observed when two subjects accidentally "locked in" an incorrect waypoint by prematurely pressing the ENT button prior to completely entering the desired waypoint ID. Thus, an unwanted waypoint with a similar ID to the desired waypoint was locked in. There is no "undo" function or editing function available. Therefore, if a waypoint is locked in accidentally, the user must delete the unwanted waypoint and re-enter, from the beginning, the desired waypoint.

Excess button presses were seen in the case of one subject when confusion arose concerning the words "activate" and "deactivate" with regard to the flight plan (i.e., flight plan must always be deactivated before it can be altered) (Task 15). When a flight plan is active the word "deactivate" appears as a menu option, indicating that the flight plan is active and can be deactivated by selecting the menu option. It appeared that the subject assumed that the words indicated current status (flight plan deactivated or activated) instead of an action.

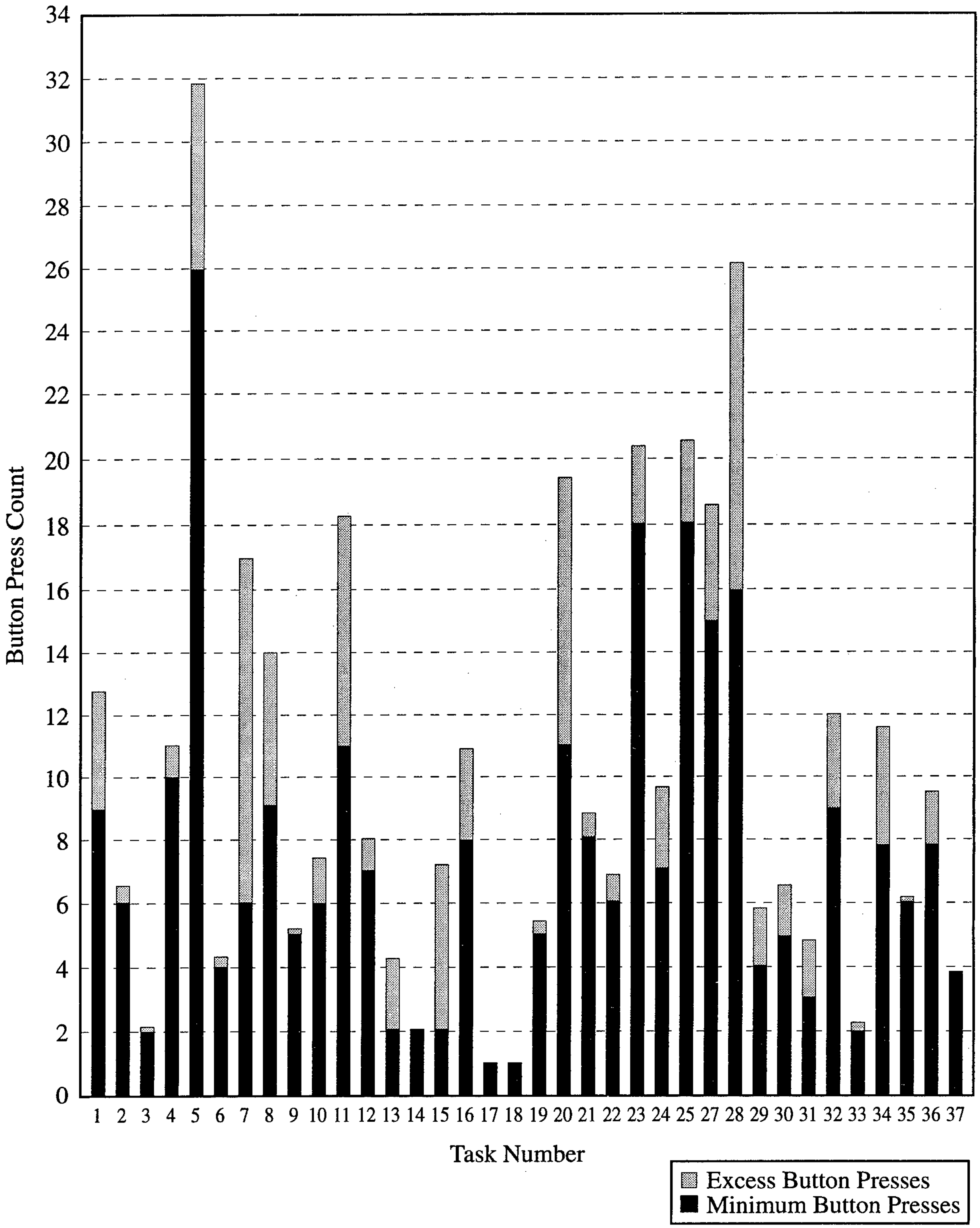

Figure 2. Minimum Button Presses Needed to Accomplish Tasks and Button Press Count Exceeding Minimum for Each Task.

Seven of nine subjects did not deactivate the flight plan before attempting to delete a given leg from a flight plan when using the waypoint menu of the moving map display. Most subjects recovered from the error, quickly deactivated the flight plan, and then followed the instructions to delete the leg from the flight plan. One subject initially did not deactivate the flight plan, thus could not delete the leg. In an attempt to determine a correct course of action, the subject exited the menu containing flight plan manipulation options and unknowingly moved the cursor in the moving map display over a waypoint (bringing up information about the waypoint–an intersection). At that point, the subject wanted to return to the flight plan manipulation menu, but was not able to access it until the cursor was moved off of the intersection on the moving map display. There was no indication given to the subject that placing the cursor over a waypoint in the moving map display would "lock out" the menu containing flight plan manipulation options. The subject's actions (not deactivating flight plan and moving the cursor over an intersection) were cycled through twice, creating much confusion as to how to accomplish the task of deleting a leg from an active flight plan.

Deleting a waypoint from an active flight plan is very similar to deleting a leg from an active flight plan. However, the subject must first deactivate the flight plan and then delete any associated legs of the flight plan before deleting the waypoint. Three subjects attempted to delete a given waypoint without first deleting the corresponding leg from the flight plan. One subject attempted this twice, even though the first attempt did not succeed. One subject deleted the waypoint successfully but then became "lost" in another mode of the moving map display after pressing the ENT button (this action brought the user to the "cursor mode" of the moving map). Normally, the subject would press ENT again to return to the "position mode" of the moving map. However, the cursor was positioned over a waypoint, thus the subject could not return to the appropriate mode as expected (similar to the subject being locked out of the flight plan manipulation menu, described above). There was no indication that placing the cursor over a waypoint in the moving map display would "lock out" access to the other map mode. Another subject accidentally deleted an incorrect leg from the flight plan. At that point, the subject realized the error but could not determine how to "undo" the action (there is no "undo" option). The subject attempted to re-insert the leg but did not do so successfully.

Error Messages (Feedback)

Textual error messages appeared only in the "calculator menu" of the graphic interface of the evaluated GPS unit. A message simply appears in a box stating that the user must first activate the flight plan before using the calculator functions. This message is quite helpful, because it stops any attempt to use the calculator functions with an inappropriate setup.

A short, single beep is given as auditory feedback when a button is pressed to let users know that their action was registered. Auditory error messages are in the form of two or three short beeps in quick succession. These two series of beeps indicate that an erroneous button press has occurred, but they do not convey information concerning the nature of the error. In the post-flight questionnaire, the statement, "If I had done something incorrectly I was given enough information to let me know what I had done wrong" was rated by subjects, resulting in an average sore of 15.57 on a scale of 0 to 100 (zero being "Strongly Disagree").

A series of two beeps occurred when subjects attempted to place user-defined waypoints over preexisting waypoints or landmarks (i.e., airports, intersections, etc.). A series of three beeps occurred more frequently than the double beeps and were usually associated with the most troublesome interactions with the GPS interface. For example, triple beeps were heard during the "double errors" discussed above. More specifically, if subjects pressed the OUT button (the correct button for this task) to remove a waypoint, and the flight plan was active, three beeps would be heard. If the subject pressed the ENT button (the incorrect button for this task) to remove a waypoint, three beeps would be heard. This leaves the subject wondering which action was incorrect since *both* seem incorrect. Both are incorrect *at the time* because the flight plan has not been deactivated. However, once the flight plan has been deactivated, the subject may be unsure if the ENT button or the OUT button should be pressed. Unfortunately, the ENT button will reactivate the flight plan, and the cycle will start over again. Several subjects, on more than one occasion, became trapped in this cycle of three-beep auditory error "messages."

Level of Consistency

Consistency within the GPS menu structure and function allocation were another focus of this study. Observed inconsistencies either hampered or prevented the completion of some intended tasks. In Table 1, take special note of the bold, bold-underlined, and bold-italic lines, which emphasize some of the inconsistencies in function allocation.

Different buttons — same function. While in the database screen and the moving map display, a user is able to retrieve site information (i.e., airport, waypoint, etc.). This information is typically too lengthy for all of it to fit on a single screen at one time, therefore a page metaphor is employed. In other words, a user is able to "flip" through various information pages, similar to those of a spiral notebook. To flip to the next or previous page in the database, the up and down arrow buttons must be pressed. However, in the moving map display, pressing the up and down arrow buttons will move the map cursor, and the user will lose the displayed site information. The user must then place the cursor back onto the prior location before the information will again be displayed. To flip through the information pages in the moving map display, the user must repeatedly press the ENT button while the cursor is located over the desired site on the displayed map. Pressing the ENT button in the database will "lock in" the presently displayed site so that information can be viewed. Therefore, using a button sequence that is appropriate on one screen may result in the loss of information on another.

While interacting with the flight plan screen, users can switch from one flight plan to another by pressing the left and right arrow buttons to proceed to a lower or higher flight plan number. However, in the waypoint menu of the moving map display, the same task is accomplished by repeatedly pressing the ENT button. Therefore, the user can only ascend to higher-numbered flight plans. This cycling through the flight plans increases the overall number of button presses required to reach the desired flight plan and the time to complete the task. If the desired flight plan number was inadvertently missed, as was observed in the study, it was necessary for the subject to toggle through all of the flight plan numbers again.

Other inconsistencies were observed when comparing the task of deleting user waypoints in the database screen with the same task as performed in the flight plan screen. In the latter, the user presses the OUT button to remove a waypoint and the ENT button to confirm the action. In the database display, the user removes a user-defined waypoint by pressing and holding the ENT button for five seconds. This problem is aggravated because the ENT button is typically associated with selecting or entering an option. Also, in the database screen, where the ENT button is used to delete a waypoint, there is no "help" information at the bottom of the display.

Feedback. Inconsistent feedback from the unit is heard when a user attempts to change a flight plan while it is still active. While in the flight plan screen, a user will receive a double beep if an attempt to change flight plans is made, but while in the waypoint menu of the moving map display, a triple beep will result. Textual feedback was located on only one screen within the software interface.

On-screen help. Another inconsistency exists in the terminology used within the "help" information at the bottom of most screens. This help information serves as a reminder to the user concerning the function of various buttons for a specific screen. At roughly half the help-information locations, the message "Press MNU to Exit" would be displayed, while the message "Press MNU to Escape" would be displayed at other areas of the interface. Both "escape" and "exit" referred to the same action: to backtrack to a higher-level menu location. Inconsistencies with terminology may lead to confusion and should be avoided. To further the inconsistency problem with regard to on-screen help, not all screens contain help information.

Head-Down Time Resulting From Interaction With the GPS Interface

Head-down time is associated with the number of button presses made, error messages received by the user, and inconsistencies experienced when using the GPS unit. The *average head-down glance time is* defined as the amount of time that subjects glanced down at the GPS unit without looking at the flight instruments or environment. In Figure 3, the average head-down glance time across subjects was commonly 10 seconds or greater. In other words, the subjects, on average, spent 10 seconds or more without glancing at the aircraft instruments or the outside environment. Performance of tasks that elicited the greatest average head-down glance times, for the most part, involved altering flight plans while in flight. *Cumulative head-down time is* defined as the sum of the mean head-down glance times per task, averaged across nine subjects (Figure 4). These measures are associated

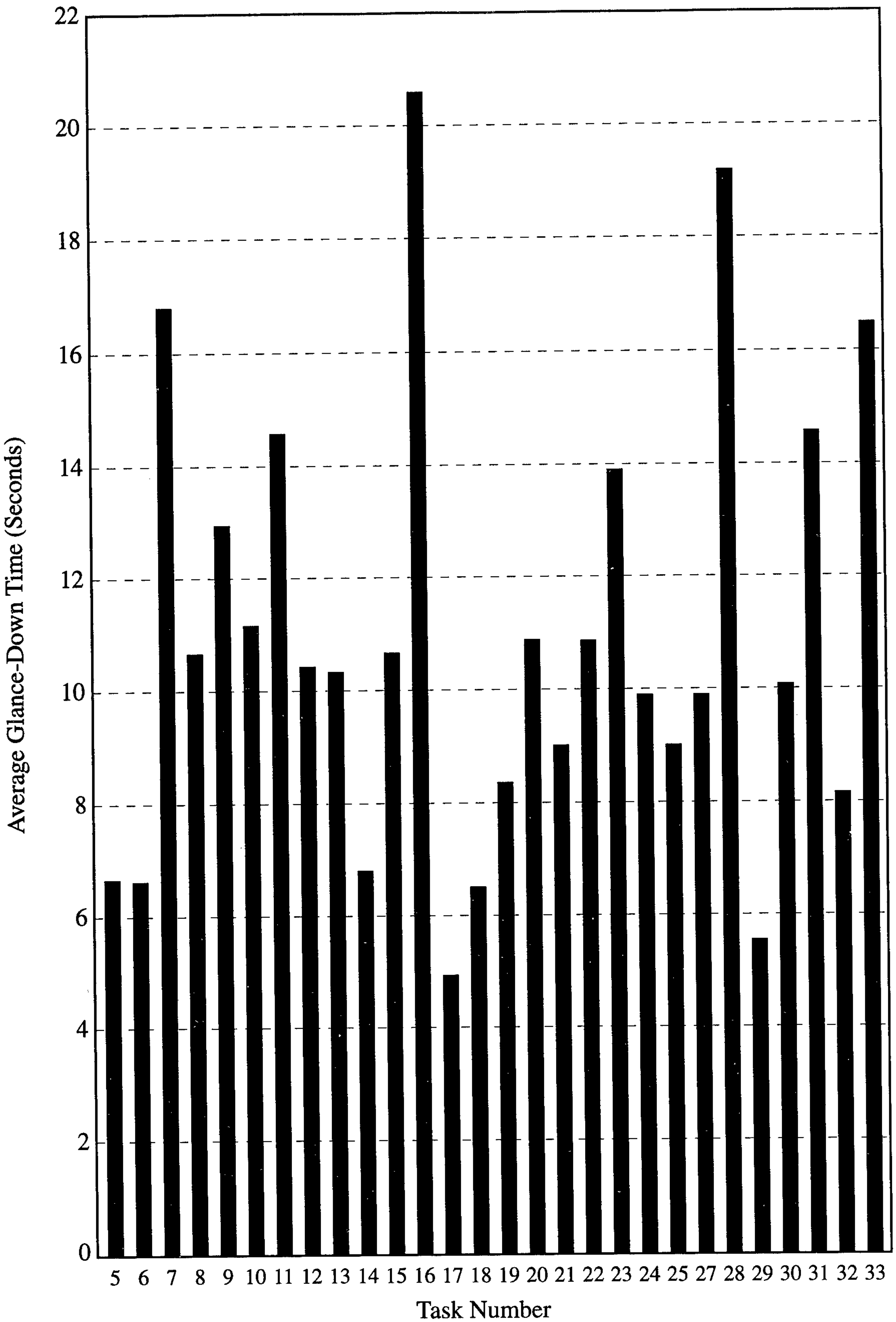

Figure 3. Average Head-Down Glance Time for Tasks in Flight.

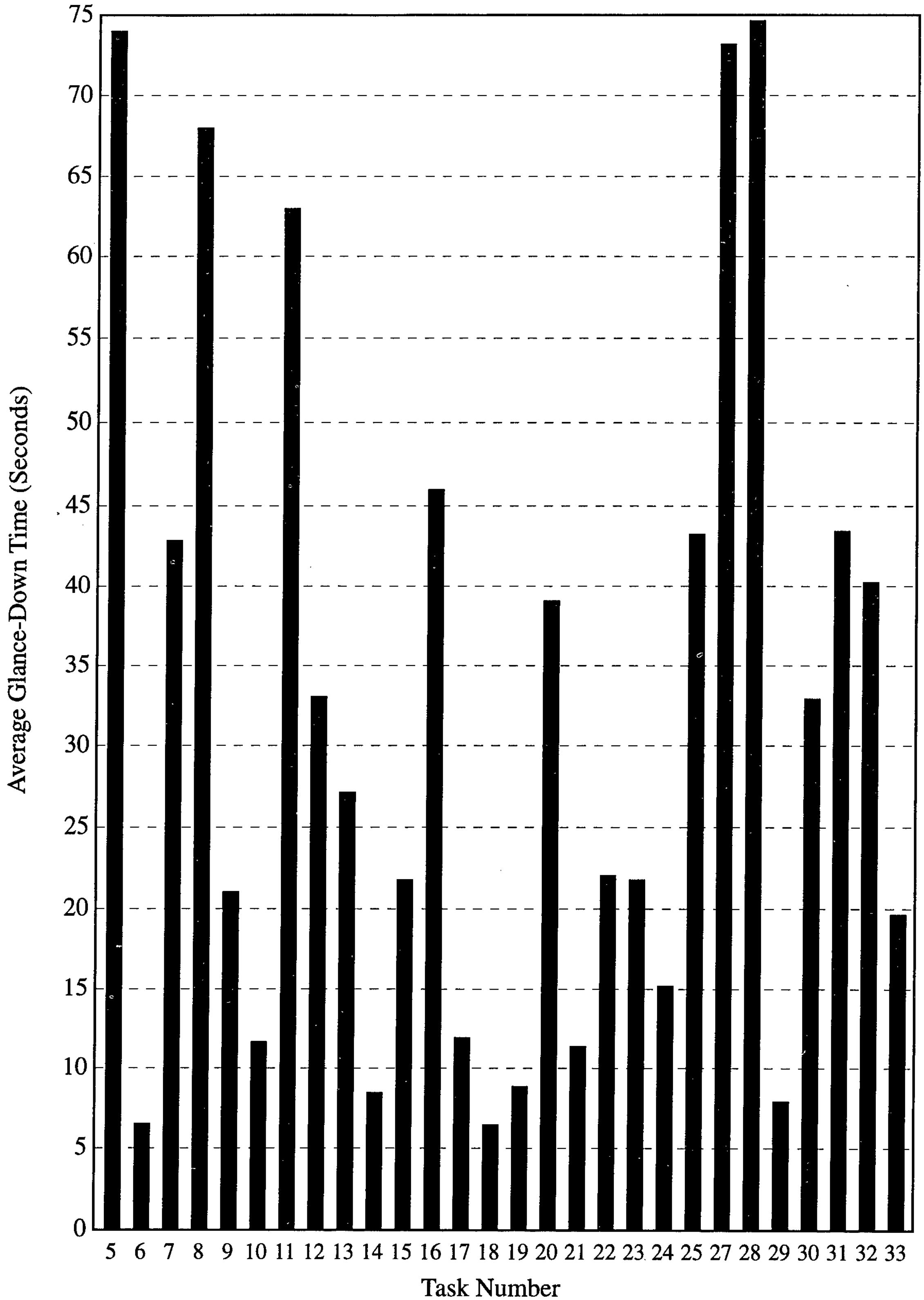

Figure 4. Average Cumulative Head-Down Time for Tasks in Flight.

with the work required to accomplish a given task and indicate how engrossed subjects became with the GPS unit during certain tasks.

An Advisory Circular (90-48C, 1983) was disseminated by the Federal Aviation Administration to make pilots aware of the actions they should perform to reduce midair collisions and near misses. Besides scanning for other aircraft, pilots must be aware of nearby obstacles, changes in terrain, etc. A valuable tool in preventing mishaps and promoting safety is visual scanning. Another important task that pilots must undertake is scanning flight instruments. Time away from scanning the outside environment and the aircraft instruments reduces situational awareness; therefore, head-down time should be minimized.

DISCUSSION AND RECOMMENDATIONS

It is suggested that in cases where some form of menu is deemed necessary to accomplish specific tasks, the focus should be on simplifying the menu structure and unit manipulation so as to allow the pilot the opportunity to attend to visual scanning tasks. The observed head-down time is cause for some concern because pilots who are not scanning the environment or aircraft instruments for relatively long periods of time may be at risk of becoming a safety hazard to themselves or others. The number of button presses necessary to accomplish certain tasks, and the number of button presses that the GPS users executed for certain tasks, in general, appear excessive and should be reduced through redesign efforts.

There are several primary factors that may contribute to the observed button-press count and head-down time in this study, including: (1) requirements for moving through the menu structure, (2) users' level of understanding of buttons, (3) ease of recovery from erroneous inputs, (4) quality and usefulness of feedback, and (5) the level of consistency within the GPS unit interface.

Ease of moving through the menu structure was rated rather positively by subjects after using the GPS unit. However, more efficient means of travel through the menu system would be advantageous. For instance, pressing a single button to return to a main menu or "central location" would be useful, as well as "direct" access to frequently used functions.

A list of the nearest airports, intersections, etc., could be accessed with a single button press allowing the pilot to choose a destination and plot a direct course to that site. However, this function could not be accessed from every location in the menu structure. It is suggested that this function be available from anywhere in the system so that a pilot under stress because of mechanical problems, for instance, can easily use the navigation aid and attend to flying the aircraft.

The subjects' understanding of the push buttons was occasionally less than desirable. This problem was due, in part, to: (1) multi-function buttons, (2) non-intuitive labeling, and (3) the lack of appropriate "help messages."

Recovery from erroneous inputs was often time consuming, occasionally frustrating, and very difficult for a subject. An "undo" function would have been useful in several cases, especially following the accidental deletion of a leg. Also, there were minimal editing functions in the flight plan screen; therefore, if a waypoint was inadvertently "locked in," the user would have to delete the unwanted waypoint, and enter the correct waypoint from the beginning, instead of editing the initial waypoint.

Feedback was only in the form of auditory tones, except for one location in the software interface in which a textual feedback message was observed. Although the auditory-error indication feedback was useful for informing users that an error had occurred, no indication of the nature of the error was given. It is suggested that textual feedback be given if an error occurs. This would prevent errors from inducing confusing cycles as seen in the "double errors" described earlier. Also, casual users may re-familiarize themselves with the system more quickly with informative feedback. The presently incorporated feedback tones were not tested at actual aircraft noise levels, so it is not known if the tones could be heard in an actual aircraft environment.

Inconsistency of push-button function appeared in several areas of the GPS unit interface. The same button should not be used for different tasks and different buttons used for the same task. For instance, it is advisable to consistently assign the ENT button to the function of entering data, options, etc. However, the ENT button was used for scrolling through flight plans, entering, deleting, and "flipping" through waypoint information pages. The OUT button was used for functions pertaining to zooming out and taking out waypoints. However, the ENT button also served to take out waypoints in one area of the system.

By following sound human factors design principles, many of the difficulties that the subjects encountered during their interactions with the GPS unit could have been avoided. It was found that the number of button presses per task, on average, was positively correlated with the length of time users spent focused on the GPS unit during a task. This finding emphasizes that a focus should be placed on ease-of-use, including the reduction of button presses necessary for task completion and the minimization of head-down time with regard to cockpit-based devices.

One salient example of how head-down glance times can affect air safety pertains to scanning the environment for other aircraft. If two aircraft are on a collision course with a combined closing velocity of 300 knots and a separation of 1 nautical mile, the aircraft will collide in 12 seconds. Therefore, if the attention of the pilots is simultaneously diverted inside their cockpits for 10 seconds, as was observed in this study (see Figure 3), the pilots of the two aircraft will have only 2 seconds in which to detect and avoid a collision.

CONCLUSIONS AND SUGGESTIONS FOR CHANGE

The findings of this usability study were very informative and provided a good indication of the design principles that should be applied to enhance ease-of-use of the evaluated GPS unit. These results may be used in conjunction with the findings from subsequent studies concerning display design to develop general performance-based guidelines. In the following section are listed some basic human factors design principles that were found to be lacking with regard to the design of the evaluated GPS unit. Application of these principles is necessary to achieve ease-of-use which, in turn, will minimize head-down time and increase safety.

Function allocation and terminology

- If the methods for activating various functions are included in a help information section at the bottom of each screen, all pertinent functions should be given in that section. It may appear that the function does not exist if it is not intuitive and is not referred to in the help section.
- A given function should be assigned to one button, not different buttons in different areas of the interface.
- Terms should be used consistently throughout the system.
- The term "escape" has no inherent meaning to a user unfamiliar with computer jargon and should be avoided for this reason.

Button identification

- Shape coding of buttons should reflect function when possible to minimize head-down time. Tactile coding, such as raised bumps or edges, would also be useful for non-visual control identification. Push-button labels should reflect the function of the button.

Feedback

- Feedback should give the user an indication of what type of error has occurred.
- Auditory tones should have some meaning (for instance, a user should know the distinction between the meaning of a two-beep and three-beep error message).
- Textual feedback would be very useful to the casual user or novice user for relaying the cause or type of error.

General

- A button which, when pressed, brings the user back to a central location in the menu structure or the most frequently used portion of the software interface would save button presses and time.
- The implementation of an "undo" function would save time and keystrokes —especially if the user is unaware of how the present state of operation was reached or is unaware of how to exit the present state.
- Features/functions should be documented in a manual, help screen, or other source. Functions that are not documented are not expected by the user and can interfere with efficient use of the system.
- An editing function should be incorporated into the design to allow alteration of erroneously entered text. This is important in the flight environment, as turbulence or distractions could cause the entering of an incorrect waypoint.
- Deactivating the flight plan before altering it may have caused more problems (extra button presses and increased head-down time) than it prevented.
- Functions that are infrequently used should be designed intuitively to avoid use of the owner's manual.

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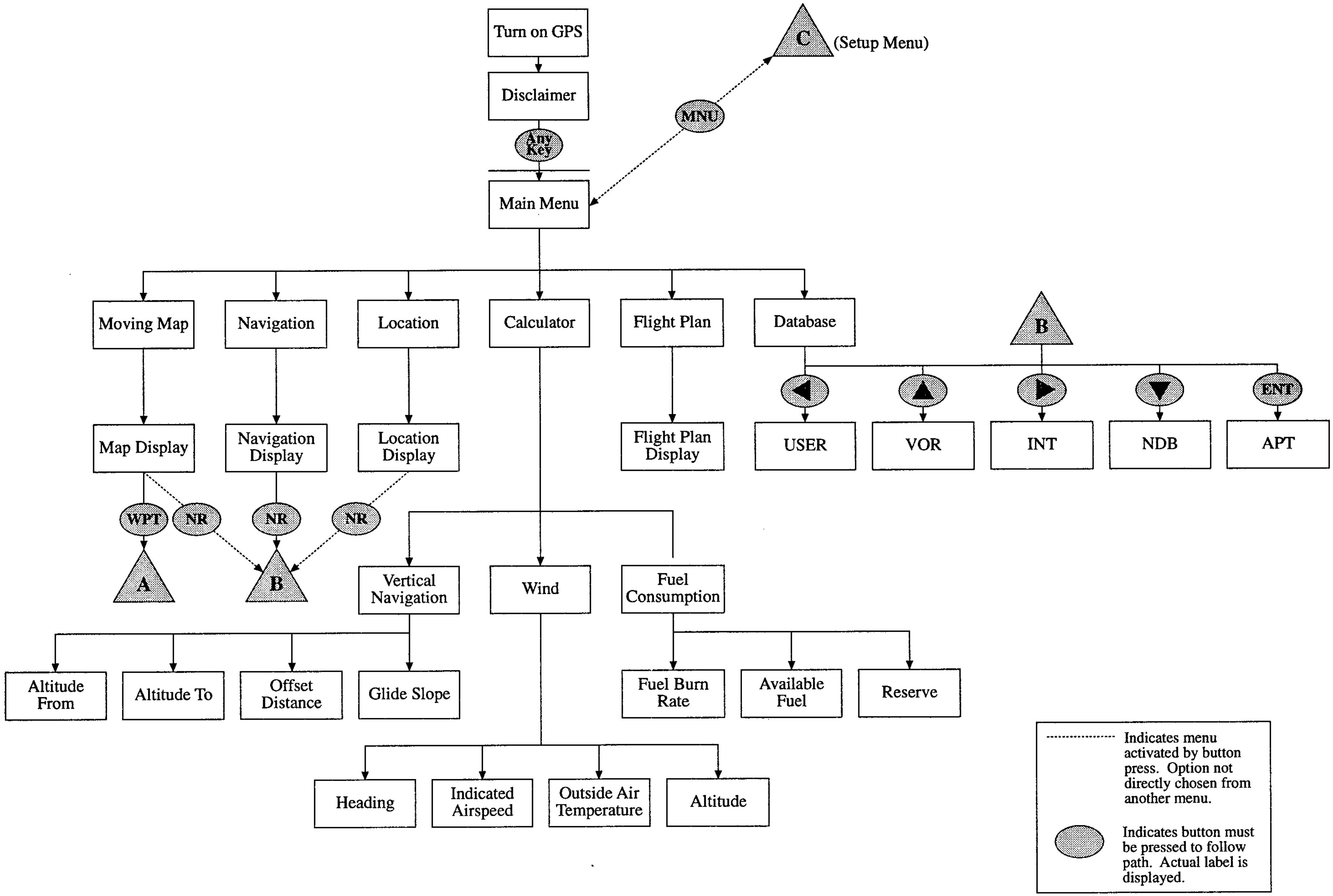
APPENDIX A

Menu Flow Diagram



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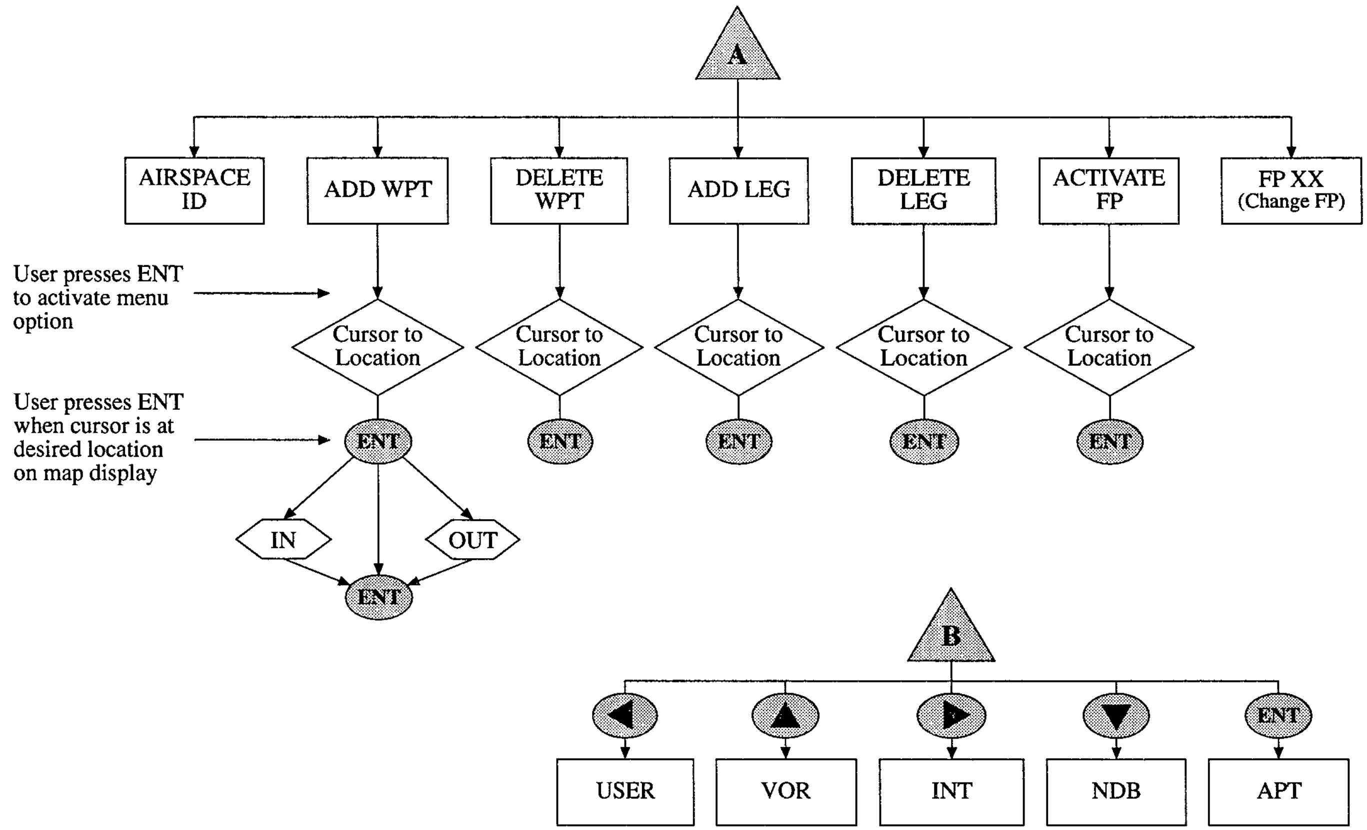
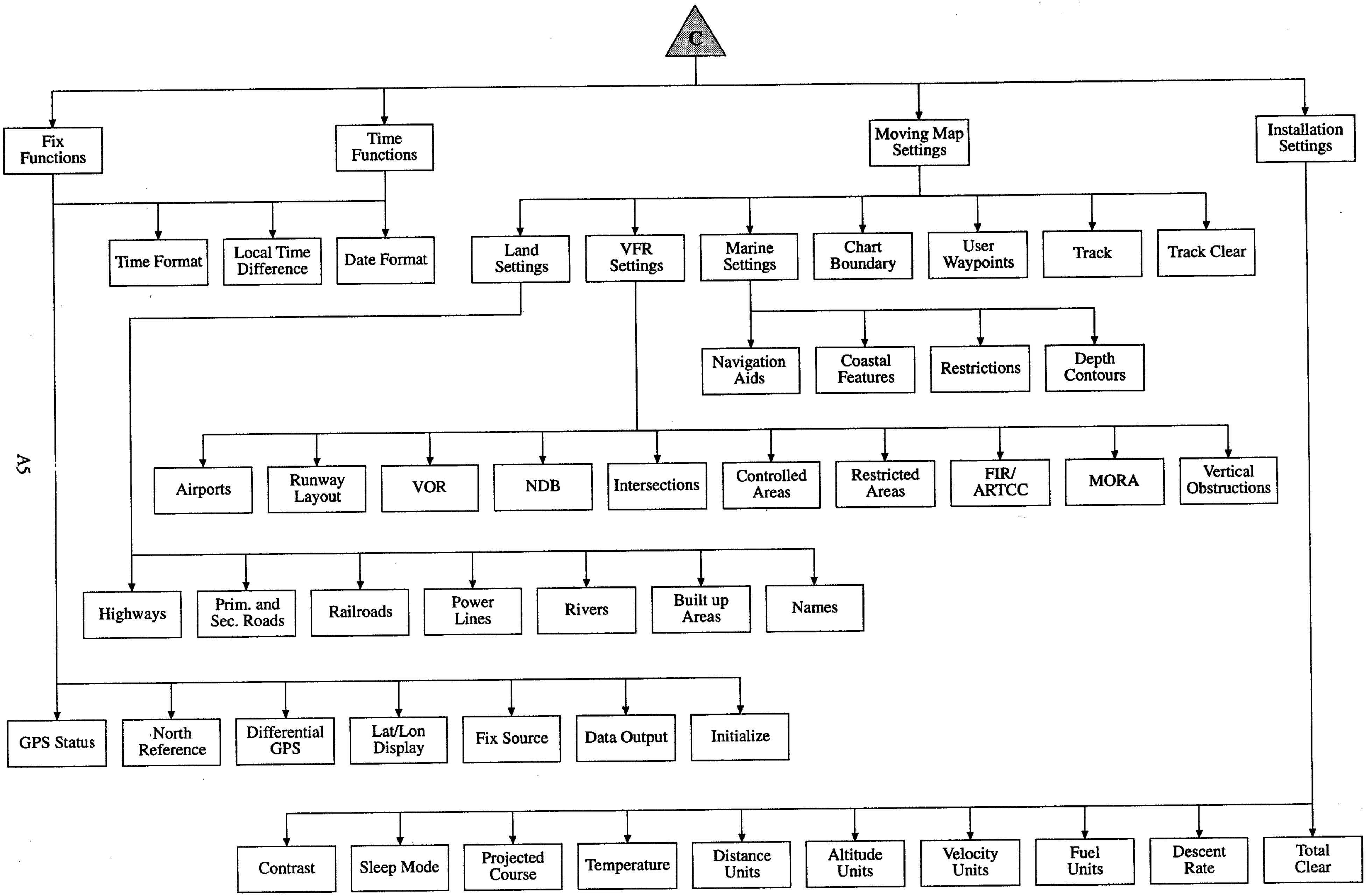
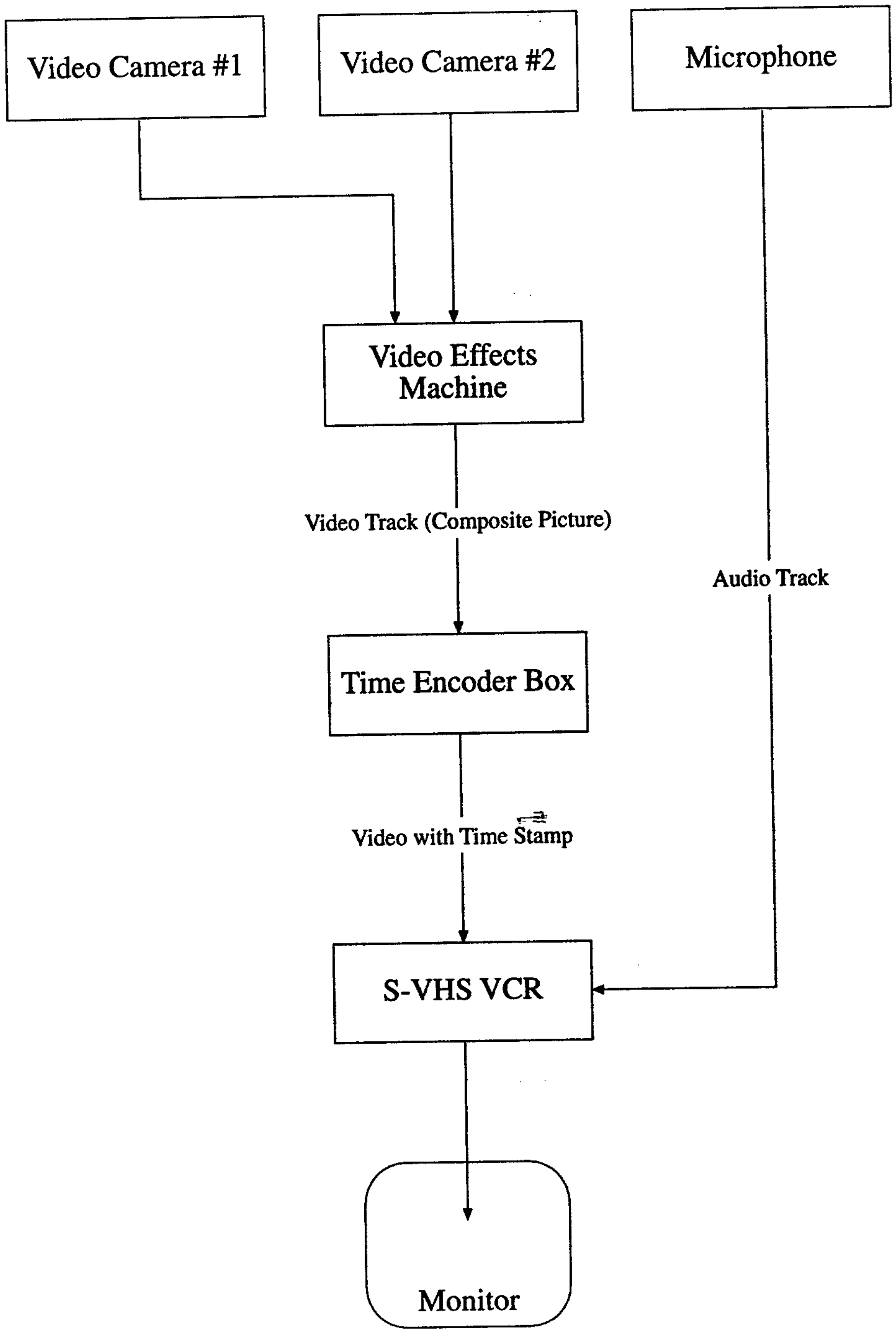

A
AIRSPACE ID
ADD WPT
DELETE WPT
ADD LEG
DELETE LEG
ACTIVATE FP
FP XX (Change FP)
User presses ENT to activate menu option
Cursor to Location
User presses ENT when cursor is at desired location on map display
ENT
IN
OUT
B
USER
VOR
INT
NDB
APT


C
Fix Functions
Time Functions
Moving Map Settings
Installation Settings
Time Format
Local Time Difference
Date Format
Land Settings
VFR Settings
Marine Settings
Chart Boundary
User Waypoints
Track
Track Clear
Navigation Aids
Coastal Features
Restrictions
Depth Contours
Airports
Runway Layout
VOR
NDB
Intersections
Controlled Areas
Restricted Areas
FIR/ ARTCC
MORA
Vertical Obstructions
Highways
Prim. and Sec. Roads
Railroads
Power Lines
Rivers
Built up Areas
Names
GPS Status
North Reference
Differential GPS
Lat/Lon Display
Fix Source
Data Output
Initialize
Contrast
Sleep Mode
Projected Course
Temperature
Distance Units
Altitude Units
Velocity Units
Fuel Units
Descent Rate
Total Clear

APPENDIX B

Video/Audio Equipment Flow Diagram



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