GLOBAL POSITIONING SYSTEM (GPS): HUMAN FACTORS ASPECTS FOR GENERAL AVIATION PILOTS

A thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Psychology at Massey University, Palmerston North, New Zealand

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I certify that the substance of this thesis has not already been submitted for any degrees and is not being currently submitted for any other degrees.

I certify that to the best of my knowledge, any help received in the preparation of this thesis, and all sources used, have been acknowledged in this thesis.

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ABSTRACT

The allied disciplines of psychology and human factors within aviation are well established. Moreover, the benefits that their research efforts have brought to the underlying theoretical and practical application of technology within aviation are well documented. The introduction of the Global Positioning System (GPS) is a new technology in this context that has not yet received much attention in terms of its human factors implications. GPS is a satellite based navigation system, available as a non-standardised "add-on" navigation system for General Aviation (GA) aircraft. While GPS has been established within the military environment for some time it has only recently been made available to the civil aviation market. To date there has been little human factors research conducted on its use by pilots, especially in the GA industry where it has rapidly become an extremely popular navigation aid. This study aimed to utilise the fundamental principles of psychology and human factors to examine GA pilots' use of GPS. Particular reference was made to the equipment design ergonomics, the psychological attitudes and behaviours displayed when using GPS, and the implications GPS has for flight safety. The study sought information to determine whether formal training was required and to suggest the format for such training. A survey of 172 GA pilots using GPS in New Zealand was carried out to investigate five research questions proposed to provide a basis for future research. The results found that GPS was rated highly for its design and ease of use, however specific areas of GPS design needing improvement were identified. GPS was rated in a similar fashion by pilots irrespective of their individual demographic sub-groupings. While the majority of pilots were found to have positive attitudes and behaviours using GPS, some users had developed negative attitudes previously associated with automation such as over-confidence, reliance, and complacency. This had resulted in certain inappropriate behaviours. These included operating without backup means, discarding standard navigation procedures such as maintaining reference to maps and charts, and navigating with GPS before gaining an acceptable level of knowledge and competency with its use. The results appeared to be generalisable to the wider pilot population. The results suggest that formalised training incorporating human factors was required for operators to use GPS to its full potential and to avoid committing errors with possible hazardous consequences.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
HUMAN FACTORS OF GPS USE

Psychology and human factors provide a framework with which to evaluate the person-machine systems and allied technologies within aviation. These closely related disciplines have gained in importance within the aviation industry through the research that they have undertaken to improve the aeronautical systems in use. Global Positioning System (GPS) is another example of new technology requiring scrutiny to ensure that it is well designed for the operators at the work face. In the past, research into the effects of equipment design upon the user has been retrospective as systems were already well in place before human factors evaluations were able to be conducted. The introduction of GPS into the General Aviation (GA) market provides an opportunity to enhance the implementation of this technology during its inception.

GPS is the most recent high technology navigation system to enter into aviation (Clarke, 1994). It is based on a constellation of 24 US Department of Defense satellites, and employs small, relatively inexpensive receivers that enable users to easily obtain highly accurate navigation guidance. GPS is available as a non-standardised "add-on" navigation system for GA aircraft.

As GPS is relatively new, there has been little research conducted on its use by pilots. However, anecdotal evidence suggests that GPS has been used quite extensively in an "un-approved" manner and that its use may have altered some pilots' flying behaviour. Changes may have occurred to the navigation strategies used by pilots, and to the decision making and judgement processes that follow. Possible negative consequences associated with using GPS inappropriately have been contemplated, and the need to identify potential hazards has been discussed by O'Hare and St. George (1994).

Civil aviation technology has typically been developed from advanced military and civil research. It has normally been initially incorporated into airline fleets, and finally, if at all, it has been introduced into GA aircraft. This process generally follows comprehensive testing, and the development of the required regulations and training procedures. GPS is an example of flight instrument implementation that reverses this trend. GPS has been rapidly adopted for GA use ahead of regulatory provisions and training requirements due to the pace of commercial technological advancement, availability, and affordability.

Introducing GPS into aviation in this way could mean that human factors considerations are overlooked, or neglected. Human factors being a discipline "that discovers and applies information about human behaviour, abilities, limitations, and other characteristics to the design of tools, machines, systems, tasks, jobs, and environments for productive, safe, comfortable, and effective human use" (Sanders & McCormick, 1992).

GPS is already approved for VFR (Visual Flight Rules) (Civil Aviation Authority, 1995a) and for Supplemental IFR (Instrument Flight Rules) (Civil Aviation Authority, 1995b). GPS is soon to be approved for Primary Means[1] IFR navigation with approach certification anticipated thereafter (Civil Aviation Authority, 1995c). It is therefore to be expected that there will be a rapid and widespread use of GPS throughout all levels of the aviation industry, both in New Zealand and worldwide. The aim of this study was to utilise the fundamental theoretical principles of psychology and human factors to facilitate the identification and subsequent redress of the human factors problems associated with the expanding use of GPS within the GA industry.

Human Factors In GPS Design

A person-machine system arranges people and machines to interact within an environment to achieve system goals. Figure 1.1 is a model of such a system with the right side representing the machine sub-system from a human factors perspective. The displays present information in a format that humans can perceive and comprehend. Controls allow an operator to alter the status of the internal equipment. From this perspective, the internal workings of the machine are considered only with respect to the

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[1] See Appendix A: Definitions and abbreviations

inputs and outputs. Human factors concentrates on designing displays and controls with an operating logic that is optimised for human use.

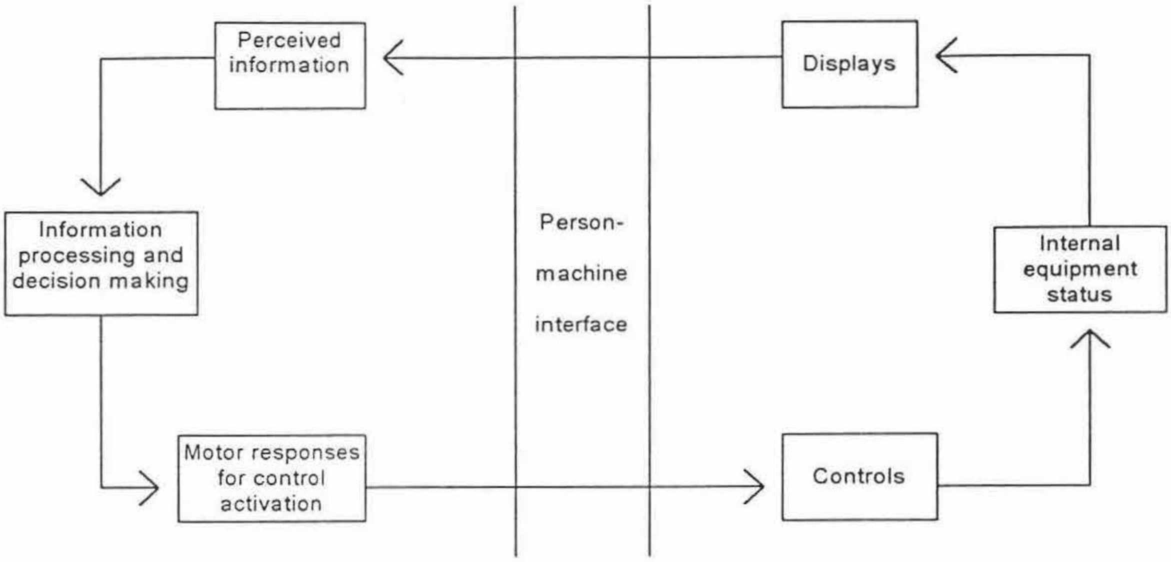

Figure 1.1 Model of a person-machine system (modified from Meister, 1971).

The left side of the model represents the human sub-system. Information is perceived from the displays, the information is processed, decisions are made, and motor responses are invoked to alter control settings and perform other behaviours as a response to the output. These are important parts of the human sub-system from the human factors and psychological perspectives.

The centre portion of Figure 1.1 represents the human-machine interface. Information moves in both directions across this interface within the closed-loop system. The facilitation of this information movement is better achieved by changing the machine design to suit the person, than by attempting to adapt the person to the design. It is easier and less expensive in the long term, to re-design and build machinery to fit the typical operator, than to try and train the operator to cope with systems that are less than ideal (Kantowitz & Sorkin, 1983). When people have to use equipment that is not designed to suit their physical and mental abilities, they are unable to work optimally and operational errors may occur. Such errors can prove to be both costly and dangerous to safety. To reduce errors, inappropriate responses, operator stress, and training requirements; controls, displays, and their operating logic need to be designed to match human capabilities. Thus, guiding principles are required to facilitate the consideration of these capabilities when designing equipment.

Design principles for GPS

GPS is an example of the rapid progress made in the field of avionics and computerisation. The design of GPS controls, displays, and the operating logic of the computer technology used, needs to reflect published guidelines for good design to ensure the optimum usability for the operators. The design also needs to be tested by the end-users to ensure that the principles apply when the equipment is used for its intended purpose.

General design principles

A useful conceptual basis for a discussion on general design principles is provided by Norman (1988). He considers many important aspects of general usability when designing equipment for human use. For example, basic requirements include having an obvious and accessible On/Off switch, with "accidental-off" prevention and a "power-on" indication. There are instances when it is dangerous to turn a piece of equipment off by mistake. An example would be losing navigation information in an aircraft on an instrument approach in bad weather. Likewise, it can be important to know whether power is reaching the equipment as it may give erroneous information when power is off, as is the case for the ADF. If a critical system has reverted to standby power, this needs to be signalled for remedial action before the standby power is exhausted.

Norman discusses of the paradox of technology where the incorporation of additional helpful functions results in a greater operational complexity when the number of functions exceeds the number of controls. Relationships between the controls and their related functions become arbitrary, unnatural, and complicated; making the system more difficult to learn and operate. This paradox is well demonstrated with advanced GPS systems. Extra complexity reduces the principle of visibility (Norman, 1988), which is the relationship between controls and functions where by looking, the user can tell the state of the device and the alternatives for action. Visibility makes relevant parts of the system evident.

The lack of visibility also contributes to mode errors (Hawkins, 1987). Mode errors occur when devices have different modes of operation and the action appropriate for one mode has different meanings in other modes. These are likely to occur whenever controls perform more than one function, or control more than one display. Mode errors are especially likely when equipment does not make the mode visible, so that the user is expected to remember the mode that has been established.

Another design principle discussed is that of mapping (Norman, 1988). Mapping is a principle based upon the strength of the relationship between two things. Natural mapping is intuitively obvious based on real world experience, physical analogies, and cultural standards. An example is knowing the direction in which to move control knobs. Appropriate mapping allows easy determination of the relationships between actions and results, between the controls and their effects, and between the system state and what is visible. Natural mappings should be used for functions; between intentions and possible actions; between actions and their effects on the system; between actual system states and what is perceivable by sight, sound, or feel; and between the perceived system state and the needs, intentions, and expectations of the user.

The construct of "knowledge in the world" is signalled by the saying "out of sight, out of mind". Real world cues are needed as a reminder of how things work rather than using "knowledge in the head" or memorised rules, procedures, and associations (Norman, 1988). Natural mapping is an example of these cues. Table 1.1 compares the features of these two types of knowledge.

Natural mappings are the basis of what has been called "response compatibility" (Norman, 1988) within the human factors field. The major requirement for response compatibility is that the spatial relationship between the positioning of controls and the system or objects upon which they operate should be as direct as possible. The controls should be either on the objects themselves or arranged to have an analogical relationship to them. In a similar fashion, the movement of the controls should be similar or analogous to the expected operation of the system. Difficulties arise when the positioning and movements of the controls deviate from strict proximity, mimicry, or analogy to the system components being controlled.

Table 1.1

Tradeoff between knowledge in the head and in the world (from Norman, 1988).

Property	**Knowledge in the world**	**Knowledge in the head**
Retrievability	Retrievable whenever visible or audible	Not readily retrievable. Requires memory search or reminding.
Learning	Learning not required. Interpretation substitutes for learning. How easy it is to interpret information in the world depends on how well it exploits natural mapping and constraints.	Requires learning, which can be considerable. Learning is made easier if there is meaning of structure to the material or if there is a good mental model.
Efficiency of use	Tends to be slowed up by the need to find and interpret the external information.	Can be very efficient
Ease of use at first encounter	High	Low
Aesthetics	Can be un-aesthetic and inelegant, especially if there is a need to maintain a lot of information. This can lead to clutter. In the end, aesthetic appeal depends on the skill of the designer.	Nothing need be visible, which gives more freedom to the designer, which can lead to better aesthetics.

The same arguments apply in terms of the relationship between system output and expectations. A critical part of an action is the evaluation of its effects. Fundamentally, this requires the timely feedback of results. Feedback is the principle where the user receives full and continuous information concerning the results of actions (Norman, 1988). Each action should show an immediate and obvious effect using an effective display. The feedback must provide information that matches the user's intentions and must be in a form that is easy to understand. Many systems omit the relevant visible parts of the actions, and even when the information about the system state is provided it may not be interpreted easily. An effective method to ensure an accurate interpretation is to incorporate graphics or pictures. Modern computerised systems such as GPS are quite capable of this type of function.

Norman (1988) discusses the designer's conceptual model versus the user's conceptual model. It is important that both have the same image of the physical system, especially where a lack of practice makes the functions difficult to use. A good conceptual model provides consistency in the presentation of operations and results; and a coherent, consistent system to aid recall.

Standardisation

There are no design standards for GPS with controls and displays differing significantly between manufacturers and models. Standardisation is an aspect of "good design" both within the specific unit and between different models manufactured to perform the same task. Standard control types, display formats, and operating logics should reduce the amount of training required to use systems built by different manufacturers. Standardisation should reduce the possibility of errors occurring when routinely or occasionally using different systems. GPS has yet to attain a standard design philosophy through evolution or imposed regulation. While GPS is developing at a rapid rate, manufacturers are producing systems that differ greatly in presentation and operation. Whilst this may be due in part to experimentation and searching for the best method, it may also be a factor of commercial marketing pressures, and in design which lacks human factors research. A problem for designers may be that GPS has many applications apart from aviation and that systems are being designed to be multi-functional instead of specialist. For example, the only difference between some marine and aviation receivers is the database installed. Standardisation appears to be a valid suggestion consistent with efficient learning and transfer of training literature, however there are problems with its application (Landy, 1989). The problems in applying standards stem from little research knowledge of the optimal information to be displayed, the optimal design for the controls, and the optimal operating logic for the system.

GPS design

It is necessary to review the GPS equipment in order to assess whether the guiding psychological and human factors principles of design have been fully incorporated. GPS is intended to give a precise three-dimensional (3D) determination of position, velocity, and time. It operates by passively receiving signals from satellites, allowing an unlimited number of users and all weather operation (Ackroyd & Lorimer, 1990). It gives real time positioning and allows continuous operation. GPS was originally designed for the U.S. military but has been made available for general worldwide use. The first major individual use of GPS for navigation with a GA aircraft was for the 1990 circumnavigation of the globe in a Cessna 310. There was only limited satellite coverage at the time, but now full coverage is available and private users around the world routinely use GPS (Clarke, 1994).

Manufacturers of the receiver/processor (referred to as the GPS receiver) have designed the equipment to track the GPS satellite radio signals and provide extremely accurate navigation information (Hofmann-Wellenhof, Lichtenegger, & Collins, 1992). Primary benefits are global 24 hour navigational coverage and direct routing capability. GPS equipment covers the extremes from minimum capability stand-alone receivers to sophisticated GPS/integrated navigation systems. The performance differences between models are small, being mostly in the calculation functions and database features offered (Clarke, 1994).

Marketing influences have extended the definition of a GPS "receiver" to include the complete device from antenna to readout display. A basic receiver has an L-band antenna to receive the satellite signal, a phase-modulated radio receiver, a data processor, and a user interface with control panel and visual output. There are several types of basic GPS receivers. They vary in complexity, satellite tracking capabilities, speed of output, and application. Generally, as receiver complexity increases, so does its capabilities. However a feature of GPS systems is their perceived overall ease of operation by the user, regardless of the receiver capabilities or complexity (Clarke, 1994).

GPS receivers can be categorised as hand-held, portable, or panel-mounted. Hand-held models are so termed as they can be held in one hand. They may also be attached to the control yoke in the cockpit with a removable mounting device (e.g. Magellan Skyblazer). Portable models are movable between aircraft but are not designed to be hand-held (e.g. Garmin 100). Panel-mounted models are permanently fitted into the instrument panel (e.g. Trimble 2000) Examples of different GPS models are shown in Figure 1.2, while Table 1.2 describes the mounting, display and control features of GPS models available in New Zealand in August 1994 at the time of this research.

Figure 1.2 Examples of GPS Models (Civil Aviation Safety Authority, 1995)

Table 1.2

GPS models and their features

MODEL	MOUNT	DISPLAY	CONTROLS
Trimble Flightmate	Hand-held	LCD	Multi-function keys
Trimble Flightmate Pro	Hand-held	LCD	Multi-function keys
Magellan 5000A	Hand-held	LCD	Alphanumeric & Function keys
Garmin 55	Hand-held	LCD	Alphanumeric & Function keys
Magellan 7000 (mmap)	Hand-held	LCD	Alphanumeric & Function keys
Garmin 95 (mmap)	Hand-held	LCD	Alphanumeric & Function keys
Garmin 75 (mmap)	Hand-held	LCD	Alphanumeric & Function keys
Apollo 920 (mmap)	Hand-held	LCD	Multi-function keys
King KLN90 (mmap)	Panel	CRT	2 concentric knobs, 8 keys
King KLN90A (mmap)	Panel	CRT	2 concentric knobs, 8 keys
Apollo Flybuddy 820	Panel	LCD	Selector knob, 9 keys
Trimble 1000	Panel	LCD	Selector knob, 10 keys
Trimble 2000A	Panel	LED	Selector knob, 9 keys
Magellan 5000	Panel	FLUOR	Selector knob, 10 keys
Trimble Transpak	Panel (portable)	LCD	Selector knob, 2 toggle switches
Garmin 100	Panel (portable)	LCD	Alphanumeric & Function keys

Note. mmap = moving map, LCD = liquid crystal display, CRT = cathode ray tube, LED = light-emitting diode, FLUOR = fluorescent display.

GPS controls

Keyboards, push buttons, and knobs are the controls typically used by a GPS system. The use of keyboards has been steadily increasing on the airline flight deck in association with computerised systems (Hawkins, 1987), however they are a relatively new phenomenon in the cockpit of GA aircraft. Hand-held GPS keyboards usually either resemble telephone touch-pads for entry of alphanumeric data, or else have a limited number of push buttons designed for picking functions shown on the display. Both methods are reported as satisfactory (Clarke, 1994), but there is no research literature to indicate which is the more optimal control method for speed and accuracy. With few exceptions, panel-mounted units make use of a combination of push buttons and concentric knobs for menu control and display selections. A key may be pressed or a knob turned to scroll through on-screen menus. Anecdotal reports appear to believe that a keyboard is easier to use except in turbulence (Clarke, 1994), but there has been no specific research to determine the accuracy of this assertion. A full keyboard takes up more space than knobs and buttons and is not found on compact portable and panel-mounted equipment. All user interfaces have more moving parts and take up more physical space than the core receiver/processor unit (Clarke, 1994). Thus, the control and display presentation is a constraining feature for reducing unit size.

Receivers using telephone-type alphanumeric keyboards require the operator to select specific letters and numbers by pressing the appropriate key, and using an arrow key to select the correct alphanumeric choice available on that key (e.g. 1, A, B, C). Other "multifunction" keyboards display menus and letters on the screen. Arrow keys are pressed to bring up the required letter or number before pressing an ENTER key to confirm the selection.

The keyphone number layout is used for many hand-held GPS control layouts. Military Standard 1472D (Department of Defense, 1989) recommends numeric keys arranged in a 3 x 3 +1 matrix with the zero digit centred on the bottom row, in order left to right, top to bottom. The keyphone layout has been shown to give higher speeds and fewer errors than the calculator layout (Conrad & Hull, 1968), (see Figure 1.3). Butterbaugh and Rockwell (1982) evaluated four keying logics suitable for aircraft sub-systems for alphanumeric character entry. They found that keying time for a logic using 36 individual keys for each alphabetic and numeric character was significantly superior to logics using push-button telephone type keyboards. Where space does not allow a full keyboard, they found that the standard telephone layout was most accurate. Research does not appear to be available on how multi-function key-driven menu systems affect operator speed and accuracy.

Keyphone

1	2	3
4	5	6
7	8	9
	0	

Calculator

7	8	9
4	5	6
1	2	3
	0	

Figure 1.3 Keyphone versus calculator layout

Control functions

The primary function of a control is to transmit control information. Controls and data entry devices must be selected and designed to be suitable in terms of sensory, cognitive, psychomotor, and anthropometric characteristics of the intended users (Sanders & McCormick, 1992). The operator's task needs to be analysed to determine the degree of accuracy, force, precision and manipulation required (Oborne, 1987), and an operator's expectations, abilities, and behaviour need to be considered when designing an effective control system that to match.

That poorly designed controls alone may lead to inefficiency and breakdown in the human-machine system was well demonstrated in a survey carried out by Fitts and Jones (1947). In a complimentary study to their work on aircraft display reading errors, they analysed 460 "pilot error" experiences in operating aircraft controls. Poor control design was related to 68 percent of the errors. The remainder were due to mistakes occurring because of poor control placement on the cockpit panel (26 percent,) or to a lack of compatibility between the display and the control (6 percent).

"Classic" examples of poor control design abound and can be found on virtually any aircraft. Some light aircraft for instance, have a separate left and right fuel tank selector rather than one selector for both tanks, which has resulted in an unnecessary forced landing for many pilots who erroneously believed that they were out of fuel. Another example of non-standardisation with the potential for confusion is the fuel selector switch. In a Piper Cub, the shorter end points to the tank in use, while in a Cessna 172 the longer end does. In a Piper Cub, the long lever on the floor on the pilot's left is the flap lever, while in a De Havilland Chipmunk the same lever is the handbrake.

Control identification can be critical in aviation applications. Fatal accidents have occurred due to the misidentification of controls and buttons resulting in the misapplication of aircraft systems, as in the Trident-Staines accident (O'Hare & Roscoe, 1990). The identification of controls is essentially a coding problem. The primary coding methods include shape, texture, size, location, operational method, colour, and labels. The choice of a coding method and the specific codes depends upon the detectability, discriminability, compatibility, meaningfulness, and the standardisation of the codes selected (Sanders & McCormick, 1992). The utility of a coding method is generally evaluated by such criteria as the number of discriminable differences that people can make, bits of information transmitted, accuracy of use, and the speed of use.

Controls are commonly classified into two groups according to their function. The first includes those that are used to make discrete alterations in the machine state (e.g. switching on or off). The second group includes controls for making continuous settings (e.g. volume on a radio). McCormick (1976) subdivides these groups into discrete and continuous activities (Table 1.3).

Table 1.3

A classification of controls by function (McCormick, 1976)

Discrete	
Activation	- for example, turning on or off.
Data entry	- keyboard letter or number entry.
Setting	- switching to a specific machine state.
Continuous	
Quantitative setting	- setting to a value along a continuum, such as tuning a receiver.
Continuous control	- continuously altering the machine state when tracking, e.g. a car steering wheel.

Push buttons

Push buttons or keys are small, single action controls normally activated by the fingers, that only operate in one direction (Chambers & Stockbridge, 1970). They range in size from the large on/off buttons on machinery to the small keypad buttons of electronic calculators. Data entry devices such as keypads are taking over the functions of more traditional controls due to the increasing use of digital circuitry and computerised electronic equipment.

Three common types of keys are available: "latching" (push-on, lock-on); "momentary" (push-on, release-off); and "alternate action" (push-on, push-off). Important physical parameters of keys are their size, separation, shape, resistance, and feedback, particularly when grouped to form a keyboard.

The limiting factor for button size is the finger dimension likely to operate the controls. A minimum diameter of 13 mm is often suggested for finger operated controls and 19 mm for those operated by the base of the thumb. Little data is available however, for comparing these suggestions and the size of the average finger-tip (Oborne, 1987). Key size affects both keying speed and errors. Size and separation recommendations are given in Table 1.4.

Table 1.4

Key design recommendations (modified from Pheasant, 1988).

	Minimum	Preferred	Maximum
Fingertip operation			
Diameter (edge length if rectangular) (mm)	6	12-15	25
Travel (mm)	3	5-10	35
Separation			
Single finger, random operation (mm)	15	50	-
Single finger, sequential operation (mm)	6	25	-
Several fingers (mm)	-	12-15	-

The key surface should normally be indented (concave) (Department of Defense, 1989). Shape can be used to distinguish between different keys.

Key resistance provides two functions: resistance and kinaesthetic feedback to prevent accidental operation. Variations in resistance can have large effects on performance (Droege & Hill, 1961). Feedback can be achieved through feel, audible click, or tone indicating that the button has been depressed correctly. Auditory feedback should be minimised due to its annoying and distracting qualities (Pheasant, 1988). Keys should have a positive action which provides tactile feedback. For enhanced feedback, an associated indicator is helpful. A high friction surface aids finger control. Capacitance and membrane-touch switches have no moving parts and are easily sealed against the elements. These buttons have minimal tactile quality and therefore some form of visual feedback is required (Oborne, 1987).

Knobs

Panel-mounted GPS receivers typically use control knobs in conjunction with keys or push buttons. Knobs are cylindrical-shaped controls which are operated by gripping the thumb and forefinger around the circumference and moving them in opposition. Knobs can be divided into three classes based on their designed function (Sanders & McCormick, 1992). These are:

1. Multiple rotation for use on continuous controls that require twirling or spinning, for which the adjustment range is a full turn or more, and for which the knob position is not a critical item of information in the control operation.

2. Fractional rotation for continuous controls which do not require spinning or twirling, for which the adjustment range is normally less than one full turn, and for which the knob position is not a critical item of information in the control operation.

3. Detent positioning for discrete setting controls for which the knob position can be an important item of information in the control operation.

It is important that the diameter is not too small to prevent it from being gripped and turned easily. Conversely, space should not be wasted by having the knob too large. Bradley (1969) determined that 5 cm was an optimum knob diameter for a variety of "standard" operations. Knobs are a standard device for making settings on a continuous scale or moving a cursor through menu items in a display. Knob diameters appear to have little effect on speed and accuracy if the depth is adequate.

Switches

Some early models of GPS used switches to make control selections. Switches can be either toggle or rotary selector switches. Toggle switches are normally either on or off while rotary switches can have many positions. Chapanis (1951) suggests the number of positions can be from 3 to 24. Toggle switches are preferred for on/off or other two state selection and can be used for three positions such as left/off/right. They can be snap loaded for momentary action. Population stereotypes (how users typically believe they should operate) can be a major difficulty for these switches (Pheasant, 1988).

Rotary selectors are the preferred control for between 2 and 24 settings. These typically consist of a moving pointer with a fixed scale which is preferred for most applications (Oborne, 1987). The grasping surface for round knobs should be serrated or knurled. Setting labels should not be obscured by hands and parallax should be minimised with the scale ends being clearly visible. Most of the dimensions for rotary control knobs are relevant for selector switches except for resistance which should snap into position as should toggle switches. An important design aspect for rotary selector switches is that the settings must be unambiguous. This can be done by moulding the entire knob or by marking the switch surface (Oborne, 1987).

Cursors

Computerised systems such as GPS, often require users to transmit a special type of continuous information termed cursor positioning. This relates to the physical location of a cursor on the display screen and is important for tasks such as selecting a word for editing or selecting a system function from a list. The information transmitted by a control may be presented in a display, or manifested in the nature of the system response. The distinction between controls and displays is now becoming blurred as technological advances create such devices as touch screens which display a computer generated control manipulated through the display itself (Sanders & McCormick, 1992).

GPS displays

GPS is an example of the current trend in technology toward flat-panel displays. The current choices for displays on GPS receivers are LEDs (light-emitting diode), LCD (liquid crystal display), fluorescent display, and the CRT (cathode ray tube). Flat panel display technology normally consists of individually addressable pixels. Displays of 10 x 10 cm have around 250,000 pixels. Solid state flat-panels have high reliability with excellent readability for high resolution displays (Curran, 1992).

Several flat-panel technologies exist including LCD which may prove the most popular. Manufacturers favour LCDs because of their low cost, low operating temperature, and low power drain. Kmetz (1987) has stated that supertwist LCD's are cheaper by a factor of two than competing technologies and that LCD's have the unique advantage of a truly low power consumption. Some of the LCD attributes still needing improvement are manufacturability, screen size, temperature range, dynamic brightness range, resolution contrast, grey scale, viewing angle and colour capability (Perry & Wallich 1985). Some LCD displays are backlit to aid night-time reading. The LED, fluorescent, and CRT displays provide their own light source and are generally more visible than the LCD types (Clarke 1994). Nearly all GPS receivers are reported to suffer from poor readability under certain lighting conditions (Clarke 1994).

An additional display factor is the format and the number of lines that can be shown. At present, displays vary from one to four lines. Dot matrix fluorescent and CRT displays have more fully formed numbers and letters and are therefore more readable than the segmented alphanumerics usually associated with LCDs. The greater flexibility of the dot-matrix format permits an infinite variety of messages using upper and lower case and special characters (Curran, 1992).

As all the data won't fit into a small display window at the same time, it is usually divided into categories, or modes, each of which may take several "pages". For example the navigation (nav) mode typically includes data such as "present position", "groundspeed", "bearing to a waypoint", "desired track", "cross-track error", and "track-angle error". Only three or four of these items can typically fit on a page at one time and be readable. There is no standardisation of what should be displayed or in what order. Ideally however, the most useful information should be available on a single page. Additional information should follow on subsequent display pages in descending order of importance or use (Clarke 1994).

GPS displays are increasingly being offered with an electronic moving-map. Moving-maps apply the GPS position, time, and velocity information to an extensive database and display the information on an electronic map. Many aviation receivers show navigation information in alphanumerics in a line-oriented display, in conjunction with a graphical course direction indicator (CDI) giving steering information towards the desired track to correct for cross-track error. The advantage of moving-map displays is the application of the "you are here" principle with the display typically showing the aircraft's location with reference to airports, navigation aids, and controlled airspace boundaries. Generally, these displays offer an adjustable scale and the ability to declutter the screen by selectively removing information. Some moving map databases display airspace information and larger advanced systems are beginning to offer detailed aeronautical map displays showing terrain and other physical features to electronically replace traditional paper charts. Moving map displays are currently at an early stage of development. However, it is likely that many GPS displays in the near future will offer a moving map display as these have the most potential to improve the pilot's mental model and situational awareness of the navigational situation by offering fully integrated navigation information at a glance.

Aircraft displays are a view of the outside world for the pilot, providing information on commands and actions as they occur. Display design should therefore ensure that the pilot is offered the most automatic and compatible representation of the current and future state of the aircraft and the environment (Roscoe, 1980). Information overload should be minimised and reading errors reduced by clearly visible and legible displays of appropriate salient information.

Accidents which result from misreading a display are often attributed to "human error" implying that the operator is to blame. This oversimplification detracts from the design features that may predispose the operator to make a mistake. The three pointer altimeter is a classic example of poor display design leading to a high rate of reading errors (Oborne, 1981). Three-pointer altimeters break altitude information into three components. The smallest needle indicates tens of thousands of feet, the next largest needle indicates thousands of feet, and the largest needle indicates hundreds of feet. Research has consistently shown that this is the most difficult type of display of altitude information for pilots to reliably assimilate, and that reading errors occur more frequently than with alternative combination analog/digital displays (Wiggins, 1994).

The primary criteria for designing visual displays is to establish what information the user requires doing the task and to display an optimal level of information in a format that is visible, legible, and intelligible. Visibility is mainly determined by the location of the display as detailed information can only be acquired from a small central (foveal) portion of the visual field around the line of gaze. Only moving objects or bold contrasts will be observed in the remaining peripheral field (Oborne, 1981).

Legibility is determined by visual acuity or the ability of the eye to resolve fine details. In general, legibility increases with: the ratio of the size of the features of the display to the distance at which it is viewed; contrast between features and background; overall illumination; certain aspects of the visual form of the object, such as typographical characteristics; the length of time for which the display is presented to the pilot (duration); and the familiarity of the "message" (Oborne, 1981). Intelligibility is determined by the meaning that the display has for the pilot. Display messages may be legible but meaningless, sometimes termed "gobbledygook" (Oborne, 1981).

Digital displays as used by GPS are preferable where the user must make an accurate quantitative reading (Curran, 1992). The low cost of liquid crystal displays (LCD's) and light emitting diode (LED) displays and the ease of using them with digital circuits also make them technically preferable. Digital displays should only be used where all but the last digit of a three or more figure reading is unlikely to change more than once every five seconds, and where the rate of change is not important (Oborne, 1981).

The polarity of digital displays should generally be positive, that is a dark image on a light screen. Radl (1980), and Bauer and Cavonius (1980) showed that performance was better with this type of screen as it was less subject to reflection glare.

Evaluating GPS design

The final assessment for the physical and functional characteristics of controls and displays rests with the user. Evaluations can be made by users following human factors guidelines to determine that the knobs, buttons, and keyboards are physically easy to locate, reach, and activate with a minimum of operating errors; and that they are functionally easy to operate. Displays can be evaluated for brightness and contrast under various lighting conditions; colour discriminability; colour coding; readability of alphanumerics; moving map appearance; quality and discrimination of auditory alarms; and alert deactivation. An evaluation checklist for standalone GPS receivers has recently been published[1] by the U. S. Department of Transportation (Huntley, Turner, Donovan, & Madigan, 1995) that uses the above parameters with reference to guidelines set out in the FAA-AC -20-138 (Federal Aviation Administration, 1994), SAE/AIR 1093 (Society of Automotive Engineers, 1969), SAE/ARP 571C (Society of Automotive Engineers, 1985), SAE/ARP 4102 (Society of Automotive Engineers, 1988a), SAE/ARP 4102/7 (Society of Automotive Engineers, 1988b), and Military Standard 1472D (Department of Defense, 1989) publications.

Human Factors In GPS Operation

GPS operation

Hand-held and portable GPS receivers are able to be moved between aircraft. They are generally powered by an AA battery pack, with rechargeable NiCad cells and aircraft power connections as optional accessories. Hand-held models can be physically held by the user, attached to the control column by a "yoke" mount, or attached onto, or on top of, the instrument panel. Portable models can be attached on top of the instrument coaming, or installed in the panel in a mount from which they can be easily removed. Panel-mounted models are permanently installed in the instrument panel and are connected to the aircraft power supply and an external antenna.

Hand-held and portable GPS receivers usually come with an extension cable and suction cup accessory with which to attach the antenna to the windscreen. Some aircraft have a GPS antenna permanently installed on top of the aircraft, as GPS performs most effectively when connected to an external antenna. Satellite reception is often inadequate within the aircraft as the radio signals cannot penetrate the aircraft hull. Large

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[1] This study was undertaken prior to publication of the checklist

manoeuvres can also cause brief shadowing of the line-of-sight signal resulting in a temporary loss of GPS information (Clarke, 1994).

GPS functions

GPS receivers offer a number of function modes with more expensive models generally offering a greater range. Function modes include "navigation", "waypoint", "position autostore", "go-to direct", "route", "nearest waypoint", "alerts", "navigation computer", "simulator", and "system status".

The navigation modes of most GPS receivers offer the same standard navigation information that can be presented in different ways depending on the particular model. Navigation information includes "destination" or "to waypoint", "bearing" or "desired track", "range" or "distance to go", "groundspeed", "track over ground", "estimated time enroute (ETE)", "estimated time of arrival (ETA)", "course deviation indicator (CDI)", "cross track error", and "time". GPS time is taken directly from the satellite atomic clocks and is extremely accurate (Hofmann-Wellenhof et al., 1992). Additionally, some GPS receivers offer extra information including "trip totals", "trip speed", "distance made good", and "track history".

Waypoint modes typically give access to an aviation database that provides coordinates and information on airports, navigation aids, fixes (positions defined by reference to a navaid), and user-defined waypoints. Generally, panel-mounted receivers have more extensive databases than those offered with portables. Some basic GPS units do not have databases, requiring the operator to manually name and enter all of the waypoint coordinates to be used. Information on airports can include radio communications (comms) frequencies, hours of operation, fuel, runway direction and length, and so on. It has been suggested that some databases are so extensive that they may be confusing to the user, taking considerable time to access and read (Clarke, 1994). Databases need to be regularly updated to ensure that accurate information is maintained. This can be achieved by replacing memory chips, renewing data cards, or updating the unit's memory via a personal computer (PC), depending on the model.

Present position can generally be stored as a waypoint by pressing an "autostore" button. This can be useful for aerial searches or for retracing an un-planned route. GPS typically displays the present position as latitude and longitude coordinates. It can also show position as a distance and bearing from a selected waypoint.

The "go-to direct" or "navigate to" function mode is designed to show the required track and distance direct from the present position to an entered waypoint. This is useful for simple single leg trips, or for quickly deviating from the route direct to a new destination. This is usually accomplished by pushing one "go-to" or "direct-to" button and inputting the waypoint designator letters, and is reported to be one of the easiest functions to understand (Clarke, 1994).

"Route" modes enable the user to create flight routes of several legs using different waypoints. Routes can normally be copied, edited, and reversed. Some GPS models however, do not enable route leg track and distances to be easily accessed for cross-checking purposes.

The "nearest waypoint" function enables the GPS to display the nearest selected waypoints such as airports or specific navaids. This function could be useful in an emergency to quickly determine the track and distance to a suitable airfield for landing.

Many GPS models have visual and aural alerts available such as proximity alerts when nearing a waypoint. These alerts can be overlooked if the user is not looking at the display when the message flashes, or in a noisy cockpit where the aural beeps used may not be heard. Whilst alert messages do remain on the screen until acknowledged, repeated messages can become annoying as they have to be cancelled by bringing up the appropriate message page and clearing it to acknowledge the message. Other alerts include track deviation, clock timers, battery low, and loss of satellite warnings.

Some models offer a "navigation computer" mode with functions such as "true airspeed" (TAS), "wind velocity", "density altitude", and "sunrise/sunset" calculations.

A "simulator" mode is offered by some models enabling the user to "fly" a simulated trip without actually moving in order to practice using the machine. A groundspeed can be entered and the display will indicate as if it is flying over a selected route.

System status functions such as "satellite reception" showing how many and which satellites are being tracked, their relative positions and signal strength, and the validity of the GPS information are normally available in various formats. Navigation is most accurate when in the "3D" (three-dimensional) operating state and requires a minimum of 4 satellites. Three satellites give "2D" (two-dimensional) information which means that altitude cannot be calculated.

Some GPS units offer many extra features such as the ability to program electronic checklists, perform fuel calculations, and plan vertical navigation descent profiles. The operation of these advanced functions however, generally involves complicated procedures requiring a number of operator control inputs.

Automation and navigation with GPS

GPS is an example of the increasing cockpit avionics automation occurring in aviation. GPS automates both manual and mental aspects of navigation previously performed by the pilot, presenting complete and accurate solutions at the press of a button.

There is a well used saying for pilots' cockpit responsibilities, "aviate, navigate, communicate" in that order (Curran, 1992). *Aviate* refers to controlling the aircraft's flight characteristics including heading, airspeed, and altitude. *Communicate* requires coordination of the flight situation with others who need to know, such as crew members, air traffic control, and other aircraft. *Navigate* involves several functions. These include tracking the aircraft's present position, progress, ground track, and deviation from the desired course. It requires determination of the wind velocity and direction, drift correction, waypoint estimates, and navigating safely through or around problematic weather conditions. Navigation involves avoiding collision with terrain, obstacles and other aircraft. It is a function of the avionics to receive and display navigation data, sense flight parameters, correlate, consolidate, and present information to the crew members, and to automate certain functions such as flight control and flight management. The aim is to enhance safety, improve flight performance and permit external communication (Curran, 1992).

The rapid transition from analogue to digital avionics, and the tremendous surge in computer processing capability has made possible a high degree of automation of avionics functions. Many aspects of flight navigation, flight control, and flight management are now automatic due to advances in computer-related technology. The process of combining sensory information within an instrument is a form of automation which includes anything that alleviates the requirement for pilots to control systems manually or to process pieces of information mentally. The increased use of automation in the form of information management is designed to decrease distractions and pilot workload. However, the rapid introduction of computer-based automation has occurred without a complete understanding of crew-machine interactive relationships (Curran, 1992). This understanding is now beginning to surface. Reducing the workload also reduces the control of the system to some extent. The trend toward automation has tended to remove the pilot from being directly involved in the physical and mental aspects of flying. Some factions have advocated this as desirable owing to the attribution of greater than 75% of accidents to "human error" (Lauber, 1989). The argument is that removing the pilot removes the greatest source of accident errors. However, many potential accidents have possibly not occurred because a pilot was there to prevent a problem developing further. For example, when simple electronics failures occur such as a popped circuit breaker or failed instrument, the pilot typically handles the problem and completes the flight safely. Humans can resolve discrepant information from separate sources and determine the valid source (Curran, 1992).

There are two possible extremes of interaction between the pilot and automatic flight systems. Either the pilot is relegated to monitoring the mostly automated avionics and handling some decision-making tasks; or the pilot will actively fly the aircraft and the automated systems will monitor various flight situation parameters for acceptability and prompt the pilot with alerts. In each case, the pilot has the role of avionics systems manager. The pilot must pre-program, select functional modes and otherwise manage these systems. The second situation equates to the GA pilot using GPS. While pilots still take an active role in flying the aircraft, they now manage and monitor navigation information rather than produce it. GPS provides navigation information acquired automatically faster and more accurately than can be achieved otherwise.

GPS is an individual avionics unit designed to relieve pilot workload with the navigation task. It reflects some of the major trends in avionics including:

1. Reduced equipment size, weight, and power consumption;
2. Increased device integration and miniaturisation;
3. Increased reliability and maintainability;

4. Higher-technology approaches to functions such as the use of satellite navigation and flat-panel displays;
5. Increased information correlation, validation, sharing and distribution;
6. Expanded functional capability;
7. Increased flight safety support;
8. Pilot workload management through automation; and
9. Greater information availability in a more intuitive graphical presentation of format and symbology (Curran, 1992).

These trends are generally beneficial, however they do produce some new problems of which GPS is an example. Reduced equipment size and increased device integration reduces the space available for controls and displays. Moreover, increased reliability and the use of high-technology may promote psychological complacency (Parasuraman, Molloy, & Singh, 1993). Increased information correlation, and expanded functional capability may produce greater operational complexity, whilst pilot workload management through automation may create manual and mental workload imbalances at critical phases of flight. Finally, greater information availability may encourage information overload.

Information presentation to pilots has a great influence on avionics development. Avionics developers have typically tried to provide more and more information to pilots without a great deal of thought about the human workload effects or intuitive information delivery (Curran, 1992). There is a clear safety risk however, when crewmembers are overloaded with information and avionics-related tasks. Navigation trends have always aimed to increase the number of ways in which pilots can determine where they are with respect to the intended flight path. With the advent of satellite-based GPS, the number of navigation systems will decrease at the same time as navigational capability will improve (Curran, 1992).

Pilots are trained to scan instruments rapidly while picking out pieces of relevant information. This rapid scan permits the pilot to control the airplane's flight attitude, to navigate precisely, and to otherwise manage the flight situation. Schearer (1986) has suggested that scanning has become more difficult with modern displays. Indicators have changed from analogue needles and dials to digital information which slows down the scan as the pilot is forced to read and process each number separately. The ease of merely noting the relative position of needle displays is now often gone. GPS displays offer a great amount of digital information to scan and process per unit of time.

GPS is an example where flight operational material such as navigation data is stored and accessed electronically rather than through printed manuals. Recent advances in optical, magnetic, and solid-state memory storage capability permit onboard storage of massive amounts of information. Even portable GPS units have databases containing navigational information for the entire world. With steady advances in this area, the paperless cockpit is possibly not far away (Curran, 1992). Then high resolution display of flight information with rapid search, scrolling, browsing, panning, and zooming, and random access will bring another wave of massive data infusion into the cockpit. This may be coupled with the existing problem of checking the validity of the presented information and encourage greater dependence upon the electronic system. Whilst paper charts and approach plates are still required as the primary reference for navigation, in future they will be a backup when electronics failures occur, even though failures are becoming much rarer (Curran, 1992).

The extent to which the above automation issues apply to GA pilots' use of GPS will be addressed in this study.

Attitudes and behaviours with automation

Cockpit automation has both positive and negative attributes to consider. Some of these have a direct effect upon the pilot's behaviour when using automated equipment. Wiener (1988) for example, lists increased reliability, accuracy, efficiency, and system monitoring ability as positive issues arising out of automation. However, he also suggests that a negative attribute is that automatic systems appear to encourage new forms of human error. In particular, these can lead to gross mistakes rather than relatively minor errors often associated with traditional manual systems. Moreover, benefits such as accuracy and reliability can also lead to problems.

Wiener and Curry (1980), and Danaher (1980), identified a problem associated with an operator placing too much trust in an automated system. This is termed "automation-induced complacency" (Parasuraman, Molloy, & Singh, 1993). One possible cause for this trust developing involves Langer's (1989) concept of premature cognitive commitment. Here, an attitude develops when a person first encounters a device in a particular context that is reinforced if it is encountered again in a similar way. Thus, by not encountering any problems after using the equipment a few times, the pilot may develop an expectation to never have any problems.

Over-reliance in the infallibility of the system can lull the operator into a false sense of security. An example is seeing a problematical situation developing but not immediately doing anything to rectify the situation due to an awareness that the equipment has built-in warning devices to alert the operator closer to the event. For example, a pilot may note that the speed is low on approach but neglect to immediately rectify this, instead relying on the stall warning buzzer to indicate when the speed has reduced too much. If, for some reason this warning does not occur or is acted upon too late, a preventable accident may occur through complacency (Wiener, 1981; Parasuraman, et al., 1993) and dependence on the equipment. Wickens (1984) believes that designers need to build in procedures to prevent the human operator from placing too much trust in the automated device. Awareness of this "complacency potential" however, (Parasuraman et al., 1993) may create attitudes to help guard against the construct.

When a task, traditionally completed by an operator, is replaced by an automatic system, the operator's level of interaction or familiarity with the task or state of the system may be reduced. There is evidence to suggest that when a problem occurs, the operator will be slower to detect it and will require longer to take control and exert corrective action if not integrally part of the "control loop" (Wickens, 1984). The increased latency and reduced accuracy of failure detection when "out of the loop" was demonstrated by Young (1969), Wickens and Kessel (1979, 1980), and Kessel and Wickens (1982). In each of their experiments, operators were required to detect changes in the dynamics of a tracking system that was either controlled manually by the operator or controlled by an autopilot. They found that detection performance reduced when the operator was monitoring rather than controlling the task.

In contrast, Ephrath and Young (1981) demonstrated the opposite effect. Detection performance improved when the operator was a monitor, rather than a controller. They suggested that this difference from Kessel and Wickens (1982) results was possibly linked to an increased level of workload for monitor superiority. Another possibility is in the use of qualitatively different failures in the experiments. Ephrath and Young (1981) defined their failures as a gradual bias in the directional navigation rather than a change in the plant dynamics themselves. Wickens and Kessel (1981) suggest that these results are consistent for superior monitoring of systems dynamics themselves when the operator is in the loop with a relatively low workload. GPS is an example where the pilot is both the operator and monitor of the system.

The role of system familiarity applies to the immediate real-time loss of information regarding the momentary state of the system. There also appear to be long-term consequences of being removed from the control loop (Wickens & Kessel, 1981). Pilots and controllers may lose proficiency as they receive less "hands on experience". Their skill remains of critical importance as long as the potential remains for them to intervene: for example, to map read following GPS power failure. Thus, reversionary practice periods are important both to retain skills and to experience the dynamic relationship between system variables.

According to Wiener (1988) automation does not eliminate the possibility of human error but relocates sources for error to a different level. This may be evident in several different situations. For example, "set up" errors are the result of incorrect system programming prior to use. Entering the wrong coordinates for the intended route into the GPS prior to flight will be a potential source of error that may go undiagnosed until a departure from the flightplan occurs.

Human error can also be evident in the manufacturing of both the hardware and software of the equipment. System bugs can prove disastrous if they provide false information at critical times. As automated systems become increasingly complex, there is a greater responsibility on the computer programmer who needs to design programs that foresee the various combinations of events that might require automated responses (Goodstein, Anderson, & Olsen, 1988). All eventualities cannot be anticipated however. If the automated fault diagnosis system cannot interpret the compound failure that occurs and alert the operator to the degradation of the information presented, then problems result due to the operator's trust in the system. If the operator believes the system information and so maintains a false hypothesis of what is occurring in the real world, then this trust may thereby induce all the consequences of cognitive tunnel vision in hypothesis testing described by Sheridan (1981). Thus, trust in the accuracy of the commercially supplied GPS database would be an example of a part of the system not directly monitored by the operator where errors could inadvertently be programmed.

The answers to issues of the fallibility of automated systems are unknown, although human factors experts have acknowledged the responsibility placed upon programmers and system designers because of this (Goodstein, 1981, Lees, 1981). It may be prudent for computerised systems to err on the cautious side in attaching confidence ratings to their own diagnostic and decision-making abilities (Buck & Hancock, 1978; Laughery & Drury, 1979).

Wiener and Curry (1980) argue that the operator's understanding of the mechanism by which the system does the job is a major determinant of how well an operator trusts an automated system. They believe that if the system is viewed as a black box that generates outputs from inputs through some unknown algorithm; it will be far less trusted than if the operator understands the procedures followed by the system. This demand usually requires an investment of training for the operator to understand, use, and trust the automated process. Conversely however, it may be that operators, completely ignorant of the workings of the machine, may see it as a black box that cannot fail, especially if they have no personal experience of the machine failing or presenting inaccurate information. This confidence in the machine's ability to unfailingly achieve the task may be a cause of automation complacency.

The evaluation of automation from the perspective of job satisfaction lies in the domain of social and industrial psychology. There is possibly as much diversity of acceptance of automated systems as there is in the operators' personalities and the capabilities of the systems themselves. For example, some pilots prefer hands-on control at all phases of flight while others prefer to use the autopilot at every opportunity. Acceptance by the user is a critical factor in the operation of a system. Wiener and Curry (1980) have presented four guidelines for producing acceptable automated systems.

1. Design the automated system to perform the task in a manner consistent with the way a user would perform it. In this manner, the operator's internal model of the automated system's performance is consonant with their own.
2. The desires and needs for automation may vary across occasions and individuals. Therefore automation should be flexibly available and not mandatory.
3. In a similar vein, automated decision systems should provide guidelines and recommendations not commands. A "forgiving" system will be better accepted by the user than an autocratic one.
4. Extensive training in the use of the automated systems should be provided so that the operator may truly appreciate its potential benefits and mode of operation and so that failure and malfunctions may be better understood.

Wickens (1984) concludes that the best system design must account for human strengths and limitations. It needs to be remembered that the human brain is complex with perception, memory, attention, and action all involved in the interaction. A well designed system needs to consider how these processes interrelate, and what limitations they may have. This will not eliminate the possibility of human error, but it will possibly remove the system designer as a contributing factor.

Workload measurement

A common justification for the introduction of automation is that it reduces operator mental workload. In some cases, this is intended to give an extra margin of safety or comfort, whereas in others, it is to free the operator for additional tasks. It can be difficult to assess the reduction in workload however, and workload may have simply been relocated to other areas. For example, GPS may relieve the mental workload of computing the aircraft's position and speed in relation to maps of the terrain, but it may increase the workload associated with programming, accessing the desired information displays from the machine, and interpreting them.

Objective methods of workload assessment are problematic when measuring the effects of automation (Harris, Hancock, Arthur, & Caird, 1995). Automation entails a qualitative change in the operator's response to the system almost by definition, with a typical reduction in overt response frequency to the primary task. Secondary tasks also need to be considered and evaluating the effects of automation on pilot workload requires a sensitive, external measure that can be applied regardless of the level of automation. No sufficiently validated set of tasks suitable for a test battery currently exist (Tsang & Vidulich, 1989).

Subjective measures are the easiest methods of measuring perceived workload at present. These methods have their problems however, and researchers need to decide on the number of dimensions, immediacy, and absolute or relative evaluation process to be used. In addition, awareness is required concerning the demonstrated dissociation between objective and subjective measures that can exist where the results from both methods can differ (Vidulich & Wickens, 1986; Vidulich, 1988; Yeh & Wickens, 1988). It appears that some combination of multiple techniques to assess workload changes with the introduction of automation is necessary (Derrick, 1988).

Information on perceived workload using GPS will be sought in this study from respondent's subjective ratings. This may be used as a basis for future experimental research into workload using a combination of qualitative and quantitative methods.

Cognitive demands of automation and navigation

Concerns exist for the roles that machines and pilots should take in present and future automation developments. Some of these concerns, such as increased mental workload, a reduction of pilots' skills, and the creation of new human errors when operating automatic systems, are well illustrated in articles by Wiener and Curry (1980); Sheridan, Fischhoff, Posner, and Pew (1983); Wickens (1984); and Wiener (1988). The main focus of research into system automation has been on the airline flight deck where the most contentious impact of automation has occurred. Arguments have centred on when, how, and what to automate with a key consideration of such decisions being the assessment of the cognitive demands upon the human operator (Tsang & Vidulich, 1989).

The new generation of electronic computerised information systems has changed the pilot's task to become more of an information manager than was previously the case. According to Wiener (1988), using automation has different cognitive demands to those needed previously, for monitoring, supervising, controlling, detecting faults, decision making, and learning how to optimally operate the equipment.

Monitoring

Monitoring is an aspect of supervisory control required for failure detection, fault diagnosis, and problem-solving in general. Monitoring involves scanning displays to keep the pilot informed of both automated and non-automated systems' status. Moray (1986) has identified several influential factors that modify the monitoring strategy of an individual. These include: uncertainty due to forgetting; the required accuracy of the observations; correlational structure of the different sources of information; the cost of the observation; and the cost of a missed observation.

Moray (1986) found that the most important factor in determining monitoring performance is practice. Experienced operators appear to develop an internal model of the statistical properties and bandwidth of the signals. As the model develops, actions become more automatic and monitoring becomes optimal. It seems that developing an internal model of the monitored process is essential to achieving effective supervisory control. To effectively monitor the performance of GPS for example, one must have some idea of the information that should be displayed, and an easy reference to the system's own reported integrity at any time.

The purpose of monitoring is to allow supervisory control to be exercised via an intelligent mediator such as a computer or another person (Moray, 1986). Three major characteristics of supervisory control have been postulated (Sheridan, 1987). These are the roles of the human supervisor, the loci of function, and the levels of behaviour. Supervisor roles are planning, programming, monitoring, taking over control, and learning from past experience. Each role has three loci of function; these are perception, decision making, and response functions. Supervisory control activities can be described by three levels of behaviour; skill-based, rule-based, and knowledge-based (Rasmussen, 1978).

Skill-based behaviour is a well learned activity such as lowering the nose and increasing thrust as a reaction to hearing a stall warning in an aircraft. These activities are generally not mentally demanding as they have a well defined stimulus-response mapping, and these are the easiest activities to automate. However, automating these activities raises concerns for "out-of-the-loop" (non-involved) familiarity and loss of skill proficiency.

Rule-based behaviour is more mentally demanding on the working memory and less automatic. For example, if the destination airfield is closed due to weather, a diversion must be chosen with regard to distance and time to get there, fuel remaining on arrival, forecast weather on arrival, suitability for landing, and so on. The response is selected by scanning a series of "if-then" algorithms held in memory. Where the algorithms can be specified ahead of time, these activities can also be automated. Knowledge-based behaviour is least suited for automation. Situations requiring this type of behaviour are typically novel or unpredictable situations where few pre-established rules can be applied. This level is the most cognitively demanding and most difficult to automate. The boundaries between skill-based, rule-based, and knowledge-based behaviours are ill-defined however (Moray, 1986). Another difficulty with Sheridan's (1987) conceptualisation of supervisory control concerns the communication between the human supervisor and the computerised systems. Further research is needed for a better understanding of the actual processes involved in the allocation of supervisory functions between human and computer (Tsang & Vidulich, 1989).

Moray (1986) regards failure detection and diagnosis as the most important of the supervisory roles. Rasmussen and Rouse (1981) also contend that the primary reason for human monitoring of automatic processes is the possibility of failures. Besides descriptive models of how failures are detected, it is also necessary to understand the internal mental models of the process being monitored. Highly trained supervisory control may not be adequate when the automatic components fail and suddenly require manual recovery. A specific concern is how the removal from active participation affects failure detection and fault diagnosis. While the response workload should be reduced by automating the inner-loop activities as in Wickens' and Kessel's (1980) multiple resource model, pilots are more removed from immediate knowledge about the controlled process. Thus, the status of the control process is derived indirectly from a large number of displays and warning signals, possibly under increased perceptual processing load. Thus, with GPS, if pilots reduce cross-checks with other navigation sources, they may have a decreased probability of detecting a fault, and therefore, greater difficulty in manually taking over the navigation tasks.

Decision making and judgement

Pilots' decision making and judgement play a crucial role in flight safety. Jensen and Benel (1977) reported that 35% of the non-fatal and 52% of the fatal GA accidents in the United States between 1970 and 1974 were related to poor pilot judgement. Some decisions that are direct results of automation include determining causes of failures, and deciding when to intervene and stop automatic actions. The decision making process is considered to be attention demanding and susceptible to memory limitations that vary with experience. Wickens (1987) has identified five major non-optimalities in human diagnosis and hypothesis testing. Firstly, Tversky and Kahneman (1974) observed that a hypothesis is often chosen based on the representativeness of the environmental cues to those that would be generated if the chosen hypothesis were true. Secondly, humans tend to treat all environmental cues as if they were of equal reliability making them ill-suited for prediction tasks (Wickens, 1984). Thirdly, as the number of information sources grow, the limitations of human attention and working memory may be so imposing that a selective filtering strategy may be employed to process multiple environmental cues (Wickens, 1984). Fourthly, humans are strongly biased by evidence that occurs early in the sequence. This anchoring heuristic (Tversky & Kahneman, 1974) favours the hypothesis formulated first. Moreover, the human confirmation bias seeks only confirmatory evidence for the chosen hypothesis and ignores information that disconfirms it (e.g. Mynatt, Doherty, & Tweney, 1977). This "cognitive tunnel vision" phenomenon (Sheridan, 1981) typically worsens during high workload situations. Finally, humans tend not to use negative information (the absence of an environmental cue) as evidence to disconfirm a hypothesis or support a competing hypothesis (Rouse, 1981). These tendencies may be important to consider in relation to using GPS. For example, the lack of an indicator showing battery reserves for hand-helds, means it is unlikely that the operator will decide that this needs checking.

Information processing for navigation

The limits of spatial working memory are often evident when people must navigate and deal with geographical information. The principles concerning the optimal relation between perception and memory in this domain can be specified with regard to frames of reference, and in the use of a map versus a list of the route to follow.

Displays depicting movement usually show some set of moving elements against the frame of a stable background. However, these displays often differ with respect to which element is moving and which is stable: that is, to the frame of reference of movement. The conventional aircraft attitude indicator for example, shows the horizon as moving and the aircraft symbol as stable. This is an "inside-out" frame of reference. The same relative motion is shown on a display that the pilot would see looking out of the cockpit. Conversely, an air traffic controller has a display of a stable map with a moving aircraft symbol which is an "outside-in" frame of reference. In different systems, there may be various reasons for selecting one frame of reference over the other. Therefore, it is not possible to assert that one is superior (Roscoe, 1980; Wickens, 1984). It is possible however, to specify three principles that can and should influence the choice of reference frames under particular circumstances. These are the constancy of reference frames, the principle of the moving part, and the compatibility with the operator's viewpoint.

Constancy of reference frames refers to the difficulty which people have in rapidly reorienting between frames of reference. This situation easily produces control errors, as the direction of movement required for the controller to compensate for a given display movement may be incompatible between different frames of reference.

The principle of the moving part (Roscoe, 1968) assumes that people have an internal model or expectation of what actually moves within a system. The moving display element should be the same and move in the same direction as the operator's expectation of motion. The stable element in the model should be stable on the display. Thus, for a remotely piloted aircraft, control is easier if the image is an outside-in picture of the aircraft rather than an inside-out picture from an aircraft mounted camera. This is because the operator assumes that the aircraft is the moving element in a stationary world. Such an outside-in image also leads to less total movement of visual elements on the display, which are often a distraction (Roscoe, 1968). Unfortunately, in navigational "electronic map" displays, the outside-in framework with a fixed north-up map can lead to problems when the aircraft is heading south. In this case, the principle of the moving part is semi-violated because a rightward control movement produces a leftward movement of the aircraft symbol on the display.

Compatibility with the operator's viewpoint can be demonstrated by the aircraft pilot viewing the moving horizon indicator of aircraft attitude (an inside-out display). In this case, the static compatibility between the outside world and the display is preserved, even though the principle of the moving part is violated through the use of an inside-out display (Roscoe, 1980).

Point to point navigation

Navigating from point to point represents one important issue in the human factors of spatial cognition. Two main methods for navigating are typically used; maps and route lists. Maps are spatial and, unless they are rotated to a heading up framework, tend to be outside-in, world-referenced displays. Route lists (statements saying "turn right", "turn left") tend to be verbal, inside-out, ego-referenced displays. If the directions "east" and "west" are used instead of "right" and "left" then these lists are considered to be world-referenced. Which of these aids is best, appears to depend upon the actual task and the likelihood of navigational errors (Wetherell, 1979).

Wetherell (1979), provides some evidence that route lists, or ego-referenced commands, are superior for actual vehicle navigation. In this case, the commanded turn (left-right) is always compatible with the operator's frame of reference independent of the momentary vehicle orientation. However, the route list is only effective when one is on track. If a navigation error occurs, a route list is of little use, whereas a map allows the original route to be regained, or a new route to be found to the destination. Planning a route thus requires a world frame of reference, such as when determining alternative navigational routes (Baty, 1976; Wickens, 1984).

Thorndyke and Hayes-Roth (1982) found that people can have different forms of knowledge about an environment. These forms, route knowledge and survey knowledge, relate closely to route lists and maps respectively. Route and survey knowledge may be achieved by navigation and map study training respectively, and show the same relative advantages and disadvantages as route lists and maps. GPS displays offer a form of route list with the advantage of always being related to the world. In addition, some GPS models offer electronic moving maps giving the user a choice of information display.

Cues

It is difficult to extract information in the absence of cues. Fowler (1980) for example, noted when analysing an aircraft crash that the absence of an R symbol on the pilot's airport chart was the only indication of the critical information that the airport had no radar. The lack of radar was highly significant as many pilots have come to depend upon it, and Fowler argued that it is more logical to call attention to the absence of this facility by the presence of a visible symbol, than by not showing the symbol. In general, the presence of a symbol should be linked to the information that an operator needs to know rather than with certain expected environmental conditions. For example, a GPS satellite integrity display indicates which satellites are being used at the time.

Memory

Information held in human working memory seems to be forgotten totally within ten to twenty seconds without rehearsal, and a considerable loss of information occurs over shorter periods. For example, digits in phone numbers can be transposed (Peterson & Peterson, 1959), as can the digits in latitudes and longitudes. Material can be retained for longer periods by rehearsal, but this competes for attention with other concurrent perceptual and cognitive activities (Klatzky, 1980; Underwood, 1976). Working memory is also limited by the number of unrelated items it can hold, ranging somewhere between five and nine (Miller, 1956). Larger groups such as latitude and longitude coordinates, exceed the capacity and are likely to have one or more items forgotten or transposed before recall occurs. Single items may be retained for a longer period without rehearsal in working memory. As more items are added however, the prevention of rehearsal causes the retention interval to decrease. These limits are potentially restrictive in many complex systems such as GPS, and could lead operators to enter perceived data incorrectly.

There are a number of properties of working memory which can be used to circumvent some of these restrictive limitations.

Chunking is when individual items are combined as a single coherent unit in long term memory. For example, the letters LOW PRESSURE form two chunks rather than 11 separate items in the working memory (Miller, 1956). The same chunking principles hold true for other strings of items such as phone prefixes, abbreviations (e.g. GPS), and latitudes and longitudes (Shulman, 1970). The close association existing between perception and memory is reinforced by the finding that a single object acts as a sort of chunk that supports the memory of its various attributes (Wickens, 1972; Wickens, 1984). As an example, Yntema (1963) found that subjects showed much better memory for a small number of objects that varied on a greater number of attributes than for many objects which varied on a few attributes. In an air traffic control problem, the altitude, airspeed, heading, and size of two aircraft are better retained than the altitude and airspeed of four aircraft, even though eight items are being held in working memory in each case. Thus, where possible, operators should be given the opportunity to consider many attributes of a smaller number of objects rather than the reverse.

A second variable that influences the loss of information from working memory is the similarity between the items in a group that are to be remembered, and between those items and other competing activities. The first of these, intragroup similarity, explains the increased probability of forgetting a string of similar looking letters than of forgetting a string of different looking ones. As much rehearsal uses an acoustic "loop", acoustic similarity between items also leads to increased forgetting (Conrad, 1964).

Yntema (1963) found that when several attributes of an object need to be retained in working memory, remembering is best achieved if each attribute has its own distinct, identifiable code different from the code of other attributes. In an air traffic control situation for example, altitude is coded in feet (5300), heading in degrees (125), and airspeed in knots (500). The codes can be made physically different in other respects such as colour and size. Such distinctions help maintain each code's unique appearance, maximising the intra-item differences, and reducing the likelihood of interference.

Another fundamental principle of information processing described by Wickens (1984) is the decision complexity advantage. This proposes that more information can be transmitted by an operator per unit time when this information is represented by a smaller number of more complex decisions, than by a greater number of simple decisions. Increasing decision complexity thus slows the speed of each individual decision, but this is more than compensated for by the increase in information processed per decision.

The decision complexity advantage has implications for operator interaction with computerised databases, or hierarchical menu selection systems such as used by some GPS receivers. Such systems can be described by a "breadth" of choice alternatives available at any one time, and a "depth" of sequential choices that must be made to reach the bottom of the hierarchical menu. Miller (1981) has demonstrated that the decision complexity advantage implies that a menu search can be completed faster for a few "broad" levels (a shallow structure), than for many narrow levels (a deep structure). Thus, the breadth at a given level should be constrained to the working memory capacity of a novice user.

Human information processing is largely limited by the capacity of human memory and attention. An obvious attentional limit in monitoring for example, is the rate at which multiple sources of information can be assimilated. In addition, effective decision making and fault diagnosis require the maintenance of several hypotheses and their corresponding prior probabilities in the working memory (Tsang & Vidulich, 1989). Human working memory has been demonstrated to have strict capacity and temporal limits, and information is rapidly lost within 20 to 30 seconds without rehearsal (Peterson & Peterson, 1959). Miller, (1956) demonstrated the maximum capacity of working memory to be 7 ± 2 unrelated items or information chunks. Thus, only a few hypotheses can be simultaneously entertained at one time in decision making.

The major cause of forgetting from the working memory is interference (Waugh & Norman, 1965). There are two types of interference: proactive interference, caused by previously stored information; and retroactive interference, caused by the most recently acquired information.

Whilst working memory is both attention and capacity limited, attention affects more than the memory mechanism. It affects the range of information processing stages from perception to response selection and execution (Tsang & Vidulich, 1989). As attention is limited, processing demands that exceed the available attentional resources will result in performance decrements. Current thinking also assumes that task difficulty positively correlates with attention levels, and that the more tasks, the greater the attention or processing resources required (Tsang & Vidulich, 1989). However, multiple resource theory (Wickens, 1984) holds that different processes use different type of resources and that concurrent demanding tasks do not necessarily compete for the same resources. One implication of this theory is that tasks that are heavily visually-based, may benefit from switching input and output modalities of some tasks into auditory ones such as waypoint proximity alerts for example. Particular stages of processing requiring heavy processing loads may benefit from automation, thereby relieving the workload of that stage, leaving resources for other needs. Thus, GPS may relieve heavy demands of rule-based manual navigation processing, thereby allowing more time for knowledge-based processing in terms of how best to use the available navigation information.

GPS training

Training for GPS has typically been limited to self teaching from the operating manual and experience (Clarke, 1994), and there are few avenues for formal training available to GPS users in New Zealand. To develop training for technologically advanced equipment such as GPS, the focus should be on the complex learning that takes place when humans acquire new knowledge and skills in training programmes or under operational conditions; and how to facilitate learning through system design.

Learning automation skills and knowledge

Learning can occur without changing performance (Zimmerman & Rosenthal, 1972) and practice is not always necessary for learning to occur. Social learning theory has provided many examples (Bandura, 1977; Rosenthal & Zimmerman, 1978) that people can learn solely through observation or by being told how something works. The operation of automatic systems such as GPS may be able to be satisfactorily learnt through demonstration from someone competent in its use. A definition of "learning" might simply relate learning to some kind of behavioural or mental "change", and it may be best to determine how, when, and under what conditions such learning occurs.

Learning phenomena can be viewed from an information processing perspective which serves as an organising framework through which to relate apparently diverse phenomena. Principles of learning and implications for training can be derived from this information processing account. Implications for practice can be focused upon and specific applications of learning principles explored. Techniques for improving the effectiveness of learning through changes in the system that the learner will be operating can then be indicated.

In general, the human information processing approach views the human as an active participant in the learning process. The information flow typically begins with some initial perception, through a series of cognitive processes, to either an observable response or merely a change in the contents of an individual's memory. The major concern is with how the information is interpreted. A distinguishing feature of the information processing approach is its characterisation of the human as an analogy with a computer system. Like a computer, the human can be thought of as a symbol-manipulating device. It consists of a mostly permanent memory containing all the data in the system; a temporary main memory holding the data currently being processed; software that are essentially lists of instructions to be executed; and a central processing unit that cycles through the instruction list.

One of the components of the human information processing system can be labelled declarative memory, or semantic memory (Anderson, 1976). Declarative memory is the system component that contains a person's factual knowledge. This kind of knowledge is assumed to be stored permanently and may decay slowly over time. Factual knowledge includes knowledge of the identity of a machine part, knowledge that 2 + 2 = 4, and knowledge of what happened yesterday, for example. A feature of the organisation of declarative memory is that information is stored hierarchically (Anderson, 1976). This hierarchical characteristic of memory organisation can be used in designing learning materials. It has been shown that humans find it much easier to remember material with a built-in organisational structure (Bousfield, 1953; Tulving & Pearlstone, 1966). It is easier still if that structure is made quite apparent (Bower, Clark, Lesgold & Winzenz, 1969). For example, in learning lists if it is noticed that some of the to-be-remembered items are components of system A and the rest are components of system B, it is easier to remember the list then if the items are thought of as a series of independent things. Instruction manuals can take advantage of this learning principle by organising the material by topic and sub-topic.

Systems training requirements

Designers should attempt to minimise the training requirements for systems that humans operate and maintain. They need to consider the ease of learning of the system. This includes both the design of the system and the instruction manual that explains it. The availability of computers in the design process allows the integration of these two system components that have normally been treated separately in the past. Nine practical applications of learning principles have been listed as a general guide to be used in designing systems that will be easier to learn to use (Kyllonen & Alluisi, 1987).

1. Learning and ultimate-performance trade-offs may be required, as system learnability and expected ultimate-performance levels are not necessarily perfectly correlated. Systems that are easy to learn may prove limited once the user has acquired expertise. Conversely, systems that are difficult to learn may never reach their high-performance design capability because the training requirements are too great to be met in practice (Card, Moran & Newell, 1983). The designer needs to evaluate the trade-offs before deciding on the final design.

2. Tasks performed by the system need to be identified so that the designer's decision criteria can be based on knowledge of how the system will be used in the operational setting. Designers need to know who, when, how, and for what tasks the system will be used (Card et al., 1983). For example, a system such as GPS, that is designed to be used by GA pilots, should not take a great deal of time to learn to operate. Many GA pilots may not have much time to invest in learning the new system.

3. Alternative methods for performing tasks should be available (Card et al., 1983). Methods for novices might include providing intermediate checks, displays of the results of intermediate steps, or menus, listing possible subsequent steps. The presentation of such supplementary information should reduce the working memory load for the novice, thereby improving learning and performance. Conversely, an expert user could be hindered by this detail. Creating novice to expert alternative methods, can maximise the system learnability and ultimately improve performance.

4. Error recovery should be available, as novices are slowed markedly when learning to operate a system if spending large amounts of time attempting to recover from errors.

Designers can eliminate this inefficiency by incorporating procedures to revert to a previous system state when one or more errors are committed (Card et al., 1983).

5. Colours and graphics to highlight changing information should be used. Further reductions of the working memory burden for the learner are obtained by cueing relevant aspects of displayed information that would otherwise need to be kept in mind. For example, new display information can be highlighted with colour, motion, backlighting or with the use of a cursor. This should not be confused with highlighting that is typical and useful in displaying critical information such as warnings (Kyllonen & Alluisi, 1987).

6. Irrelevancies should be eliminated from displays, as the displays serve as important aids to memory, and should not be used to portray unnecessary information. Non-essential information draws attention otherwise used for processing task relevant information. The designer can improve comprehensibility by limiting the presentation of information to that critical to the learning or performance task (Reder & Anderson, 1982).

7. Abstract information should be avoided by using concrete information. Graphic symbols and pictures can be more powerful than words in communicating large amounts of information, and they carry an additional advantage of greater memorability (Shepard, 1967). Designers should attempt to express information pictorially whenever possible. Moving-map displays are a good example of this principle in practice.

8. Elaborate rationales for procedural instructions should be avoided. Lists of procedures should clearly specify what the operator should do. Reder and Anderson (1980), suggest that elaborate rationales may impede learning the steps in procedural instructions in the same way that irrelevant text impedes learning the main points of a passage.

9. Conditions for practice and testing should be created, as acquired knowledge and cognitive skills decay slowly over time. Even the best learned skills must be practised to maintain high levels of performance (Schneider, 1985). Simulator functions built into the GPS system are one example enabling this practice to occur.

Flight Safety Implications

GPS has lethal implications for misuse, due to the context of its operation within aviation where operating errors could result in fatal accidents. Three main dimensions of GPS use have particular implications for flight safety, namely system design, user attitudes, and user behaviours.

The design should be generally in accordance with established human factors guidelines to enable ease of use, and to minimise training. Many of the design issues concerned have been discussed. User attitudes are important for flight safety as poor attitudes can encourage inappropriate behaviours with consequent undesirable results. Poor attitudes previously associated with automation such as over-reliance, complacency, and over-confidence have been discussed. Acceptance of the system is an important attitude to investigate as this can determine the motivation which users have towards learning to use the system and to operate it in a proficient and safe manner. Behaviours while using the system are arguably the most important determinant for flight safety. It is possible that basic procedures associated with navigation and safe flight may be altered when using GPS. These include lookout and scanning routines; navigation monitoring, cross-checking and map-reading; pilot workload; route following; risk-taking; error detection and decision making.

The consequences of GPS use for flight safety in the GA environment can only be determined by examining GPS design in conjunction with the actual attitudes and behaviours of pilots when flying with GPS. Such information can then form the foundation of the knowledge necessary to determine areas of concern that require more specific research.

Research Questions

This review of the human factors issues associated with using GPS raises a series of questions for this study to address for which answers appear to be unavailable in the current literature. The previous discussion suggests that an initial evaluation of how GPS is used by GA pilots should consider the validity of the design from the user's perspective to achieve the nominated task effectively and safely, and to identify any design problems with GPS equipment. It should examine pilots' attitudes towards this new automated system, and their behaviours when using it. It should consider appropriate training for GPS operation. Finally, it should identify any possible hazards to flight safety associated with current GPS design and use.

These are framed below into five research questions designed specifically for investigation by this study:

1. Are GPS design features in accordance with established human factors principles?
2. What are GA pilots' attitudes towards GPS?
3. How do GA pilots behave using GPS?
4. What training is required for GA pilots to safely use GPS?
5. Are there any flight safety hazards associated with GA pilots use of GPS?

Proposed study

The rapid introduction of GPS without the knowledge of how it is being used could mean that human factors considerations are overlooked. This research aimed to examine GA pilots' use of GPS with particular reference to the dimensions of design, attitudes, and behaviours, and their implications for flight safety. This examination would yield information to determine whether formal training was required and to suggest the format of any such training. A survey of GA pilots using GPS in New Zealand was carried out as an exploratory study to investigate the above research questions, and to provide a basis for future research.

CHAPTER 2

DEVELOPMENT OF THE SURVEY INSTRUMENT

The "GPS User Survey" questionnaire was designed by the researcher as similar instruments suitable for modification were not available in the literature. It was developed to obtain demographic, attitude and behavioural information on GPS users, and to obtain ratings on the GPS units' navigational functions, controls, and display design and usability.

A major challenge was achieving a well designed and constructed instrument that avoided the problems that have in the past discredited many studies that used questionnaires (Berdie & Anderson, 1974). Designing a questionnaire specifically for this study follows Berdie and Anderson's (1974) contention that each study using questionnaires is unique. The purpose of each questionnaire and the type of information sought will vary and needs to be tailored to fit the particular circumstances of that study.

Berdie and Anderson (1974) list many advantages for the use of questionnaires in research. These include the ease of establishing contact, mass respondents, the ease of completion, the lack of interviewer bias, ease of tabulation, familiarity of method, minimum time scale, uniformity of item presentation, low cost, and identification of areas for further study. They also indicate limitations that can be minimised with careful design, such as low response rates, reliability and validity difficulties, and the limitations associated with question complexity.

Survey Design

The survey instrument was designed to examine the five research questions developed from the review of the human factors issues involved in the use of GPS by GA pilots. The development of the survey research was in accordance with the recommendations of Meister (1985). These were to: identify the data requirements; determine the characteristics of the population to be sampled; develop the questionnaire; pretest and revise the questionnaire; determine the required sample size; determine the administration procedure; collect the data; analyse the data; and finally to report the results.

Identification of the data requirements

The study was designed to investigate GPS users' rating evaluations of their equipment, attitudes, and behaviours. Quantitative analysis requirements would be satisfied by obtaining data in a rating scale format. Within the work environment, rating is by far the most frequently employed subjective measurement tool (Meister, 1985). This quantification of subjective information would enable easy coding, and statistical comparisons to be made between demographic sub-samples of the population. Qualitative data would also be acquired in the form of open-ended questions for a greater depth of information and as a basis for determining areas for further research.

Determination of the population characteristics

The population of interest was all New Zealand pilots who operated a GPS in-flight. Potentially, this included GPS owners and non-owners, and both private and commercial pilots. The number of GPS units in New Zealand was unknown, as accurate records of units sold by the distributors were unavailable and some units have been imported privately. Discussions with leading retailers by the researcher resulted in an estimate of approximately 500 units in use in the country at the time of the study. Even though GPS technology was still relatively new in New Zealand, the number of units in use was growing quickly as they became less expensive, offered improved features, and received more advertising. The number of users was estimated to be well in excess of the number of GPS units as many were installed in aircraft flown by several pilots, and owners often share their portable equipment. There were 8018 licensed pilots in New Zealand at the time of data collection (G. Butler, Civil Aviation Authority, personal communication March, 1995) and anecdotal evidence suggested that approximately 10 percent of these used GPS when they flew.

The value of any survey results is in terms of the ability to generalise them. This depends upon the representativeness of the sample of respondents. Sample representativeness is uncertain without high response rates and random sampling techniques, or coverage of the entire population of interest (Meister, 1985). This study faced the difficulty that demographic details of the population of interest were unavailable. Maximum coverage of the possible population was attempted by advertising the survey directly to *Airways Corporation* flight publications subscribers, in *New Zealand Wings* magazine, and to flying organisations. It was envisaged that a representative sample of users would reply to these advertisements and participate in the study.

Instrument development

The main areas of information sought covered the demographics of the users; GPS physical design; usability of the controls; display perception; functions used; data entry methods; system checks; operating problems; usability of the instruction manual; required operating knowledge; training needs; and user behavioural changes.

To initially formulate questions, interviews with several GPS users were conducted to gain knowledge about the systems, operations, and problems that would be investigated with the questionnaire. Issues raised by O'Hare and St. George (1994), and Confidential Aviation Incident Reports on GPS (Bureau of Air Safety Investigation, 1994) were also reviewed to assist in determining the questionnaire content. Additionally, the researcher used several popular GPS models to gain familiarity with their design and operating features.

Questionnaire items were then organised within the main dimensions of design, attitudes, behaviours, and training; into sections on demographics, design, controls, displays, functions, data entry, attitudes, behavioural changes, and training requirements.

Demographic items included questions regarding the user's age, sex, flying licences, ratings, and flying experience with and without GPS. It was conjectured that there may be differences in attitudes towards the use of GPS by age group, licence type, or experience level. The demographic information would also be useful to determine the respondents' sample representativeness in comparison with known characteristics of the general pilot population's age, sex, and licence breakdown.

Design items included questions on the overall rating of ease of use; and rating general aspects such as size and shape, weight, antenna connection, power sources, accessories, ruggedness, one-handed operation, physical use, yoke mounting, and the positioning of GPS units.

Control items included questions concerning the rating of keys, knobs, and cursor movement.

Display items included questions concerning the rating of readability, characters, illumination, warnings, symbols, moving maps, and power indications.

Function items included questions rating the helpfulness of the "simulator", "navigation computer", "moving map", "database", "go-to direct", "route", "alert", "nearest airport", "groundspeed", "cross-track", "course deviation indicator" (CDI), "distance", and "position" GPS functions for flight planning and in-flight.

Attitudinal items examined pilots' confidence with GPS.

Behavioural items investigated the type of flights where GPS was used; the frequency of using GPS instead of a chart; cross-checks carried out; and changes in workload, map reading, lookout, awareness, distance flown, flight frequency, bad weather operations, and navigation methods used.

Training requirements included questions on the training received and needed; the usability of the user manual; and the level of knowledge needed for GPS operation.

The instrument consisted of rating scales and open-ended items. Rating scales are a psychometric scaling method of successive intervals. A majority of the studies reviewed found that results obtained from the use of rating scales were comparable to those produced by other methods such as forced-choice or paired-comparison techniques (Greenberg, 1963; Greenwald & O'Connor, 1970; and Scott, 1968). Each rating scale has two components: a description of the behaviours to be considered (the continuum) and a set of alternative responses from which the rater must select. Landy and Farr (1980) state that rating scales are the most common method of performance rating as they are easily developed, and more versatile than objective performance techniques and other psychometric methods.

Rating Scale items have certain advantages as part of a questionnaire (Meister, 1986). When properly constructed, they reflect both the direction and degree of opinion or attitude. The results are also amenable to analysis by conventional statistical tests.

Interval rating scales permit relatively fine discrimination by the respondent. They usually take less time to answer than other types of items, and they can be applied to almost any topic. The disadvantages of rating scales include greater vulnerability to biases and errors than other types of items. Their results may imply a degree of precision and accuracy that is not warranted (Oppenheim, 1992).

Ratings were used to measure performance qualities; operator attitudes; quantifying the adequacy of system features; and evaluating the output of the system. The rating scale used a continuous line to graphically represent the continuum of the dimension. Written adjectives represented end-anchored polar opposites for the scales. Seven-point Likert scales have been used for this study with numbers 1 - 7 denoting the scale divisions and intervals representing equal orders of magnitude of the measure, such as "always, sometimes, never". This was a relatively simple scale anchored on the basis of the author's judgement and trialed in the pre-testing phase. An example from the survey of a rating scale item is:

"Overall, how easy is the GPS to use?

not at all 1 2 3 4 5 6 7 extremely"

A small number of open-ended items were incorporated within the questionnaire to obtain qualitative data for determining the range of alternative responses to a particular issue; to give a more complete picture of the issue; and to identify areas for future study.

Open-ended items have several advantages (Meister, 1985). They permit the expression of intermediate opinions that closed items would not permit, as well as the expression of concerns that may not have been identified previously. They may provide unique information, and they are easier to ask for the novice questionnaire developer unaware of possible alternative answers. Open-ended items allow the possibility to determine what is important to the respondent. An example from the survey of an open-ended item is: "What problems have you had using the GPS?"

Disadvantages associated with open-ended items also exist. They can be time consuming and take some effort. Some respondents may answer that they have no problems rather than take the time to describe those problems. Open-ended items often leave the respondent to determine what is relevant and therefore, the intent of the question may be misinterpreted, thereby making the item unreliable. Finally, open-ended questions require analysis by someone with a substantial knowledge about the questions content and they are very difficult to code for computer analysis (Meister, 1985).

Lengthy questions were avoided as otherwise, the structure could have become complex, thereby making the questions more difficult to comprehend. Dyer, Matthews, Wright, and Yudowitch, (1976, cited in Meister 1985) report a series of studies on item difficulty that support the intuitive logic to keep the questionnaire simple.

Particular attention was paid to the wording of questions for which the data was being collected because of the high frequency of misunderstanding which occurs even when using simple terms (Berdie & Anderson, 1974). The wording of questionnaire items is a critical consideration in obtaining valid and reliable responses. Three questions administered by Payne (1951) to three matched groups, differed only by the use of "might", "could", or "should". The percentage of "yes" replies were 63%, 77%, and 82% respectively. The nineteen percent difference between the extremes would probably have a large impact upon the conclusions of most studies.

Questionnaire items were checked for grammatical and factual correctness. The questions were presented as fully as necessary to allow the participant to answer validly without having to infer anything essential. Items were written as neutrally as possible allowing the subject to select the direction of preference. Response alternatives were checked for clarity as to what the respondent meant when answering. Care was taken to ensure that the questions were framed positively and that there were no double-negatives. Positive versus negative wording has been compared in the literature. Dyer et al., (1976, cited in Meister, 1985) advised avoiding the use of negatives in questions. Loaded and leading questions; embarrassing or self-incriminating questions; and compound questions were also avoided. The questions were written to be specific and unambiguous.

Response alternatives were written to agree logically and grammatically with the question, and if possible to be parallel in structure. Where it was not known whether all respondents had the experience to answer a question, suitable alternatives such as "do not use", or "not applicable", were supplied. Most items generally required only one response to be selected and this was clearly stated in the instructions. In the few cases where more than one response could be selected per item, this was clearly indicated to the respondent.

The number and order of response alternatives was considered as these may influence the response. Dyer et al., (1976, cited in Meister, 1985) reported that respondents tend to choose the first response alternative in a set more than the others; poorly motivated respondents tend to select the centre or neutral alternatives within rating scale items; and that presenting the positive pole of rating scale response alternatives will improve the reliability of the responses while decreasing their validity.

Selecting modifiers for response alternatives required some consideration. The adjectives, adverbs, or adjective phrases chosen had to be understandable and in order to represent equidistant points on continuum, they were selected so that the subject viewed them as equal intervals along the continuum. Dyer et al., (1976, cited in Meister, 1985) report a number of studies that have been conducted to determine the perception of commonly used words and phrases. As a result, there are scale values and variances for words and phrases that can be used to order the response alternatives. These published scales were adapted for use in the present survey.

Response alternatives were selected according to the purpose of the questionnaire and how the data would be analysed. Descriptors were selected to match the question. For example, where the question asked "How easy is the manual to use?", descriptors were "not at all" and "extremely". Descriptors on different continuums were not mixed. The term "average" was not used with quantitative or qualitative terms such as "excellent" or "good" as this may have defined the average performance of the item (Meister, 1985). The wording of response alternatives on balanced scales was parallel where possible, such as "extremely poor" and "extremely good". It was noted that some pairs of parallel phrases are not equally distant from a neutral point, or from other phrases in terms of their scale values. Thus, although they may be perceived as symmetrical opposites, some parallel wording may not always be perceived as equally-distant for, and against, the response alternatives (Meister, 1985).

Some words are difficult for subjects to use when answering and some appear to have two or more distinct meanings (Meister, 1986). Moreover, some descriptors are more ambiguous than others with higher variability of responses and thus, only descriptors with small ranges or standard deviations were used. When balanced scales with two to five descriptors were sufficient to describe the respondents' distribution of attitudes and evaluations, the item was constructed using a term and its literal opposite for two of the terms. More extreme pairs were achieved by using modifiers such as "extremely" or "much" with these terms. Once the decision was made on how extreme the scale end points should be, the descriptors were selected with the highest and lowest scale values. For a midpoint response alternative, the descriptor was neutral in meaning. Some of the commonly used midpoints are not as neutral as might be expected. Meister (1985) notes for example; that while it may be desirable to have equal intervals between rating scale response alternatives in order to perform analyses based on numerical values or weights; that this is often impossible as many words have not been assigned scale values. When scale values are available, the response alternatives can be selected as being equally distanced apart. Table 2.1 shows three verbal descriptors used in this survey to denote degrees of frequency.

Table 2.1

Degrees of Frequency

Phrase	Scale Value	Interquartile Range
Always	8.99	0.52
Sometimes	4.78	1.83
Never	1.00	0.50

Source: Modified from Meister, (1985).

A refined set of phrases can be obtained using scale values and standard deviations to select response alternatives. In general, these terms should have small variability, parallel wording, and their scale values should be as far apart and equally distant as possible. Dyer et al., (1976, cited in Meister, 1985) provide many tables listing phrases which have scale values including standard deviations where available. Table 2.2 is an example of such a table used in this questionnaire. To ensure clarity, only the end and mid-point response alternatives were given in the instructions for the four 7-point rating scales developed (Meister, 1985) (Appendix C).

Formulating the questionnaire

A funnel approach similar to that recommended for the structured interview by Cannell and Kahn (1953) was taken for question sequence. Broad questions were asked before specific ones as the subject can generally answer questions more easily and validly if they have had an opportunity to consider the broader view first. Dyer et al., (1976, cited in Meister, 1985) suggest that within a series of items, the order of questions be varied to avoid one question contaminating another. Immediately preceding questions may put the respondent into a particular frame of reference or mental set.

Table 2.2

A set of response alternatives selected so phrases are at least one standard deviation apart and have parallel wording.

Response Alternatives
7. Extremely good
6. Remarkably good
5. Good
4. So-so
3. Poor
2. Remarkably poor
1. Extremely poor

Source: Modified from Meister (1985).

The biographical questions seeking demographic data were placed at the end of the questionnaire. Meister (1985) suggests that difficult or more sensitive questions be asked later. Easier, non-threatening, and relevant questions such as "which models were used" were asked first to build rapport and to lead the participant into the survey.

Items were grouped into the categories of usage, design, controls, displays, helpfulness, functions, power sources, data entry and output, behavioural changes, general, training requirements, problems and hazards, and demographics.

Instrument pretesting and revision

Questionnaire pretesting is essential if faults are to be found and rectified (Oppenheim, 1992). The rating scales developed for use in the questionnaire were examined for psychometric soundness. After the pre-test, each item was reviewed and its inclusion in the instrument justified. Items that did not add significant information or that replicated other items were deleted.

The questionnaire was initially reviewed by two pilots and two non-pilots to check question wording, interpretation, answer options, and general design. It was modified, then trialed on six pilots representing both experienced and inexperienced GPS users. Each pilot was given a critique sheet (Appendix D) to record difficulties with the questionnaire while completing it. Three of the pilots were interviewed as they completed the survey to ensure that their interpretation of the questions agreed with the designed intent. The results of the trial were analysed and the questionnaire was rewritten to incorporate the results. Changes included using a seven-point rather than a five-point rating scale, rewording, reorganising, and removing some of the questions. The resulting modified questionnaire was again given to the trial pilots, and no further changes were found to be needed.

Survey Instrument

The final version of the instrument used for this survey was a 125 item questionnaire, consisting of a combination of seven-point Likert-scale items and open-ended questions (Appendix B). The survey contained sections on GPS design and operation, user attitudes and behaviours, GPS training requirements, difficulties with GPS operation, and user biographical details. The main dimensions of the instrument were physical design, attitudes, and behaviours using GPS.

Sample And Setting

Sample size determination

The value of the results in terms of the ability to generalise them, depends upon the representativeness of the sample of respondents. It is important to determine the nature of the subject sample and its size. Where polling on a population-wide basis is involved, there are formulae for determining the sample sizes required to secure reliable data (Meister, 1985) but pragmatic factors such as time, money, and population availability, often constrain sample size. The author determined that a sample size of 20% of an estimated 800 GPS users should be a valid representation of the population assuming a random response to the survey. A sample greater than 160 was therefore the aim.

Administrative procedure

As the exact size and composition of the population of interest was unknown, the problem was how to reach aviation GPS users. It was determined to inform as many pilots in New Zealand as possible that the study was being conducted and to encourage those pilots using GPS to request a survey be sent to them. This assumed that the users would be motivated enough to return a request card informing them of the study and to then complete and return a survey that was mailed to them. Results can be distorted if the target group is not sufficiently motivated to respond adequately. Response rates can even be influenced by the title of the questionnaire. The word "survey" appears to be more favourably received than does the word "questionnaire" (Berdie & Anderson, 1974). The author believed that the motivation to take part in the survey should be relatively high as the technology being studied is new and interesting to aviation users. Intuitively, a questionnaire that is of interest to the respondent is more likely to be completed and hence, returned.

Several suggestions from Meister (1985) of ways to improve respondent motivation and to possibly significantly increase the return rate of the mailed questionnaires were followed. Advanced notice of the survey was given to potential respondents by advertising through *Airways Corporation* and *New Zealand Wings* (Appendix E). The special role of the respondent was acknowledged in the cover letter (Appendix C), which explained the purpose of the study and detailed the voluntary and confidential participation requested. Whilst volunteers are normally more motivated to complete questionnaires, their replies may be biased for this reason (Berdie & Anderson, 1974).

Confidentiality is required to encourage response, and full, honest replies to questions (Berdie & Anderson, 1974). The feedback of study results was offered to participants with individuals being informed that the results of the study would give them information on GPS use in New Zealand. A small incentive for participation was given in the form of an opportunity to win one of twenty-five subscriptions to *New Zealand Wings* magazine. Self-addressed "Freepost" envelopes were sent with the questionnaires. Follow-up reminders were sent to those who did not return their surveys within three weeks.

Questionnaire administration time was determined in advance by pretesting. There is contradictory evidence about whether shorter questionnaires are returned more often than longer ones (Berdie & Anderson, 1974; Meister, 1985; Oppenheim, 1992). Although relatively long, feedback indicated that the average 35 minute completion time was acceptable, as the content was interesting to the respondents.

Measurement

Questionnaire reliability

Estimates of reliability based on the average inter-item correlation within a test concern the "internal consistency". The size of the reliability coefficient is dependent on both the average correlation among items and the number of items. The longer the test the more reliable it tends to become (Nunnally, 1978). Coefficient alpha is the basic formula for determining internal consistency reliability. Nunnally (1978) believes that coefficient alpha should be obtained first as it sets an upper limit to the test constructed in terms of the domain sampling model. He suggests that correlations between alternative forms such as strictly parallel tests and the coefficient alpha are often very close for objective tests. Reliabilities of .70 or higher suffice for early stages of research such as this, with reliabilities above .90 not worth the effort to achieve (Nunnally, 1978).

Cronbach's Alpha and Parallel internal consistency reliability analyses were run on the questionnaire. Values for the 95 rating scale items were Alpha .84, (Standardised item alpha .87); and parallel reliability .84, (unbiased estimate .85).

Standardised item alpha's for each section were: design .69 (11 items); controls .86 (10 items); displays .86 (8 items); functions .67 (13 items); and behaviours .74 (12 items). The internal consistency reliability values were considered to be satisfactory, in accordance with the guidelines proposed by Nunnally (1978).

CHAPTER 3
METHOD

Respondents

Completed questionnaires were returned by 172 respondents. Of these, 166 were GA pilots, five were military aircrew, and one was a helicopter crew member. Only three of the GA pilot respondents were female. The respondent's ages ranged from 21 to 71 years (M = 42 years, SD = 12 years, n = 169). Three respondents did not supply biographical information. The respondents' flight experience is listed in Table 3.1.

Table 3.1

Flight experience in hours

	M	*SD*	*Range*	*n*
Hours in last 12 months using GPS	119	151	0 - 998	167
Hours in last 12 months	263	230	0 - 998	167
Instrument hours	380	849	0 - 5,000	163
Hours using GPS	265	477	3 - 4,000	166
Grand total flight hours	3664	5039	80 - 25,000	167

Cases with missing data were deleted resulting in some sample size variations

Grouping respondent's experience with GPS in flight hours: 29% had used GPS for 50 hours or less, 19% had used GPS between 50 and 99 hours, 34% had used GPS between 100 and 499 hours, 11% had used GPS between 500 and 999 hours, and 5% had used GPS for greater than 1000 hours.

Grouping respondent's experience with GPS in months: 14% had used GPS for fewer than six months, 34% had used GPS for six to twelve months, 29% had used GPS for thirteen to twenty-four months, and 22% had used GPS for longer than twenty-four months. GPS was used by 24% of respondents one to two days per month, while 43% used GPS more than seven days a month.

GPS models were owned by 60% of the respondents, with 7% having owned more than one GPS. A preference for a particular model of GPS was indicated by 46% of respondents. More than one model of GPS had been used by 36% of the respondents.

Instrument

The instrument used was the "GPS User Survey" (Nendick, 1994). The survey was 14 pages long, and consisted of 125 rating scale and open-ended items plus biographical details.

Procedure

Data collection

The survey was advertised on a freepost-return card sent through the Airways Corporation flight-supplement distribution system to 4,900 Airways flight publications subscribers (Appendix E); by advertisements in the July, August, and September issues of *New Zealand Wings* magazine; and by personal contact from the researcher to flying organisations and individuals. Through these means, the attempt was made to contact as many New Zealand aviators as possible who had operated a GPS unit while flying.

Surveys were mailed to 227 pilots who responded to the advertisements. An information sheet (Appendix C) was attached to each survey as a cover letter explaining the research and how to complete the questionnaire. Each survey had an addressed freepost envelope attached for its return. A reminder letter (Appendix F) was sent to all respondents who did not return their survey after two weeks. The reminder letters increased the overall return rate by 30%.

The total survey return rate was 78%, with 177 returns from the 227 surveys mailed out. Five respondents did not complete the survey, leaving 172 valid returns.

Data Analysis And Management

The administrative details of respondents requesting and returning surveys were recorded in a spreadsheet database for follow-up purposes. Respondents were contacted by telephone if they neglected to answer any items to ensure that missing data was minimised. Each returned survey was given a unique identification number, and the biographical information was removed from the questionnaires and stored separately. Access to the survey data was restricted to the researcher to maintain confidentiality. The researcher used a DOS data entry program to write a data entry routine to simplify data entry and reduce data entry errors. Data was coded and entered into a data file that was checked for accuracy by the researcher before analysis. Data screening to check for normality, missing data, and outliers, preceded the descriptive and inferential analyses that were conducted. Rating scale data was treated as interval data and ANOVA tests were determined to be an appropriate primary analysis method (Graziano, 1993). An exploratory factor analysis within the instrument's main dimensions was deemed appropriate for a secondary analysis of the data as there was an adequate item to sample size ratio (Bryman & Cramer, 1994).

CHAPTER 4
SURVEY RESULTS

A total of 172 cases were available for analysis. Cases with missing data were deleted from individual computations resulting in some sample size and degrees of freedom variations between analyses. Quantitative item ratings were on a seven-point Likert scale with a score of one the extreme negative rating, a score of four the neutral rating, and a score of seven the extreme positive rating for each continuum. The undifferentiated sample was analysed for general descriptive data trends initially, and one-way Analyses of Variance (ANOVAs) were conducted subsequently to investigate sub-sample rating differences. Demographic sub-samples were examined for significant differences on the basis of age, ownership, licence type, instrument rating, instructor rating, GPS experience, and flying experience. Design sub-samples were also examined for significant rating differences on model type, control type, and display type. An exploratory factor analysis (FA) was conducted within the instrument dimensions of design, attitudes and behaviours. ANOVAs were conducted to investigate sub-sample rating differences on the resulting factor variables. Descriptive and inferential results are reported within the survey instrument groupings and respondents' qualitative responses are summarised throughout as appropriate.

Data Reduction

When a number of statistical tests are conducted on the data, it is commonly accepted that the level of alpha be reduced a priori from the standard .05 to a more conservative .01. Techniques such as the Bonferroni Statistic exist to statistically adjust the critical alpha (Bryman & Cramer, 1994), but due to the exploratory nature of this study this did not appear to be necessary. Instead, for the reader's information, the ANOVA results have been reported at their level of statistical significance to four decimal places when below .05. The requirement to balance Type I with Type II error has been considered in the interpretation of the results. Whilst Type I error is the rejection of the null hypothesis when it is true, Type II error is the acceptance of the null hypothesis when it is false (Tabachnick & Fidell, 1989). The probability of making a Type II error in safety related research needs to be balanced with its consequences (Harris, 1991). However, this study was investigating for trends with statistical significance for further research and not specifically testing any hypotheses, and an initial one-way ANOVA examination of the sub-groups was considered to be adequate within these considerations.

To further investigate the research questions, a multivariate approach was deemed appropriate, in order to simultaneously examine as many associations as practical, whilst minimising the probability of a Type II error. Thus, a principle components factor extraction and varimax rotation was used which enabled a solution with adequate scientific utility, consistency, and meaning for interpretation (Tabachnick & Fidell, 1989). The number of items versus the number of subjects within each dimension was deemed adequate for such an examination, being greater than five subjects per variable and 100 individuals per analysis (Gorusch, 1983).

Sample Demographics And Representation

The sample comprised over 20% of the estimated population of 800 regular GPS users in New Zealand, and included both fixed-wing and helicopter licence holders. Of these, 40% held private pilot licences (PPL's), 48% held commercial pilot licences (CPL's), 1% held senior commercial pilot licences (SCPL's), 9% held airline transport pilot licences (ATPL's), and 2% were military aircrew. Grouping by age, 18% were in their twenties, 25% in their thirties, 31% in their forties, 20% in their fifties, 3% in their sixties, and 2% in their seventies. Instructor ratings were held by 40% of respondents. Instrument ratings were held by 47% of respondents. Agricultural ratings were held by 7% of respondents.

The sample was compared with demographic information on the New Zealand population of pilots with lifetime licences, holding a current medical certificate (G. Butler, CAA, personal communication February, 1995). A Chi-square analysis (Appendix H2) showed that the sample did not vary significantly from the sex distribution, χ^2 $(1, N = 169) = 4.02, p > .02$; instrument rating distribution, χ^2 $(6, N = 169) = 13.4, p > .02$; the instructor rating distribution, χ^2 $(6, N = 169) = 16.5, p > .01$; or the flying licence distribution, χ^2 (3, N = 162) = 10.5, $p > .01$. The sample did vary slightly but significantly from the age group distribution, χ^2 (7, N = 169) = 21.8, $p < .01$. Overall, the sample size seems adequate, and the sample composition appears to be generally representative of New Zealand pilots. Thus the results of the survey should be generalisable to the total population.

GPS Control And Display Design Features

Overall, respondents rated GPS fairly highly for ease of use on a scale of one to seven "not at all" to "extremely", (M = 5.6, SD = 1.0, N = 171). This result was unaltered when analysed by demographic sub-samples, or by the GPS categories of hand-held, portable, and panel-mounted models (Table 4.1).

GPS model popularity

Table 4.1 shows the frequency and percentage of GPS models used by respondents to this survey. Garmin 100 portables, Garmin 55 and Trimble Flightmate hand-helds were the most popular models.

Physical mounting of GPS in the cockpit

Hand-held models were either attached to the control column by a "yoke" mount (Figure 1.2), physically held by the user, or occasionally held onto, or on top, of the instrument panel with a bracket or with Velcro™. Portable models were either attached on top of the instrument coaming by a bracket or with Velcro™, or installed in the instrument panel in a mount from which they could be easily removed. Panel-mounted models were permanently installed in the instrument panel.

On a scale of one to seven "never" to "always", yoke mounting was rated as "always" used by 67% of operators using hand-held GPS models, while 18% rated as "never" using a yoke mount (M = 5.5, SD = 2.4, n = 76). Preferences were reported by 59 users. A yoke mounting was preferred by 40 users, while 12 users preferred to attach the GPS to the instrument panel or on top of the instrument coaming, and seven preferred to physically hold it.

Table 4.1

GPS usage by model and type

Model	*n*	Percent
Hand-held		
Trimble Flightmate & Flightmate Pro	33	19.2
Garmin 55	29	16.9
Garmin 95 (mmap)	4	2.3
Apollo 920 (mmap)	4	2.3
Magellan 5000A	2	1.2
Garmin 75 (mmap)	1	0.6
Magellan Skymap 5000 (mmap)	1	0.6
Sub-total	**74**	**43.0**
Portable		
Garmin 100	52	30.2
Trimble Transpak	8	4.7
Sub-total	**60**	**34.9**
Panel-mount		
Magellan 5000	13	7.6
Apollo 820 & 820C	9	5.2
Trimble 2000	6	3.5
King KLN90 & KLN90A (mmap)	4	2.3
Trimble 1000	3	1.7
Sub-total	**35**	**20.3**
Not specified	3	1.7
Total	**172**	**100.0**

mmap = moving map

Those using yoke mounting commented that they did so to keep their hands free, to maintain the display at a reasonable reading distance, and to keep the GPS secure. Some users commented that they found the GPS caused them difficulties when it was yoke mounted, including having to look down to read the display, the mounting obstructing them in some way, or obscuring other instruments. Most of those holding it did so because their control column did not fit a yoke mounting. Only one respondent reported a preference for physically holding the GPS in flight, when a yoke mounting was available. Two respondents stated that they considered either holding or yoke mounting a GPS unit to be dangerous (Appendix G).

Preferences for the best GPS mounting position were given by 157 users. A preference for a GPS to be centrally mounted high in the instrument panel where it could be seen and operated easily from both seats was given by 112 users, 28 preferred yoke mounting, 14 preferred on top of the instrument panel coaming, and 3 had no preference. Those preferring panel-mounting mentioned that this afforded a better instrument scan, less looking down into the cockpit, better physical security, accessibility of the controls, and less clutter of power and antenna cables. Those preferring a mounting on top of the coaming mentioned the importance of an outside lookout while scanning the GPS display as their main rationale. Those preferring the yoke mounting found that this was suitable for single pilot operations, that the small displays were closer for readability, and that the controls were closer for data entry (Appendix G).

GPS control design

GPS controls were used to enter data and to access GPS programmed functions. GPS models were grouped into four control categories. These are multifunction keys, (e.g. Trimble Flightmate & Apollo 920); alphanumeric and function keys, (e.g. Garmin 55 & Garmin 100); keys and knobs, (e.g. most panel-mounts); and toggle switch and rotary selector, (e.g. Trimble Transpak). Table 4.3 shows the frequency of these groupings in the sample. Table 4.4 shows the respondents' mean overall ratings for GPS control features. All of the ratings were in the "good" to "very good" range.

One-way ANOVAs were conducted on the general design items using sub-sample categories (Appendix H3). When compared on the mounting categories of hand-helds, panel-mounts, and portables for antenna security, hand-helds ($M = 4.8$, $SD = 1.7$, $n = 74$) rated significantly lower than portables ($M = 5.8$, $SD = 1.3$, $n = 57$) and panel-mounts ($M = 5.6$, $SD = 1.3$, $n = 32$), $F(2, 166) = 4.4$, $p = .014$.

When compared on the mounting categories of hand-helds, panel-mounts, and portables for flying by day, portables ($M = 5.5$, $SD = 1.3$, $n = 60$) rated significantly lower than panel-mounts ($M = 5.9$, $SD = 0.7$, $n = 35$) and hand-helds ($M = 5.9$, $SD = 0.9$, $n = 74$), $F(2, 160) = 8.4$, $p = .0004$.

These results suggested that hand-helds were more likely to have had reception problems through insecure antenna connections, and that portables were not as user friendly as hand-helds and panel-mounts overall. All other sub-sample comparisons of means showed no further significant differences.

Table 4.3

GPS grouping by control type

Control grouping	*n*	Percent
Alphanumeric & function keys	89	52%
Multifunction keys	37	21%
Keys & knobs	35	20%
Toggle switch & rotary selector	8	5%
Not specified	3	2%
	Total 172	**100.0**

One-way ANOVAs were conducted on the control rating items using sub-sample categories (Appendix H4). When compared on the control categories of multifunction keys, alphanumeric keys, and keys and knobs for key size; multifunction keys ($M = 6.0$, $SD = 0.7$, $n = 37$) rated significantly higher than alphanumeric keys ($M = 5.4$, $SD = 1.2$, $n = 88$), and keys and knobs ($M = 5.4$, $SD = 0.9$, $n = 34$), $F(2, 156) = 4.6$, $p = .0116$.

When compared on the control categories of multifunction keys, alphanumeric keys, and keys and knobs for key spacing, multifunction keys ($M = 5.9$, $SD = 0.7$, $n = 37$) rated significantly higher than alphanumeric keys ($M = 5.3$, $SD = 1.3$, $n = 88$) and keys and knobs ($M = 5.2$, $SD = 1.1$, $n = 34$), $F\ (2, 156) = 4.5$, $p = .0128$.

When compared on the mounting categories of hand-helds, panel-mounts, and portables for key size; hand-helds ($M = 5.8$, $SD = 0.9$, $n = 73$) rated significantly higher than panel-mounts ($M = 5.4$, $SD = 0.9$, $n = 34$) and portables ($M = 5.3$, $SD = 1.4$, $n = 56$), $F(2, 160) = 3.1$, $p = .0489$.

When compared on the mounting categories of hand-helds, panel-mounts, and portables for key spacing; hand-helds ($M = 5.7$, $SD = 0.9$, $n = 73$) rated significantly higher than portables ($M = 5.3$, $SD = 1.4$, $n = 56$) and panel-mounts ($M = 5.2$, $SD = 1.1$, $n = 34$), $F(2, 160) = 3.4$, $p = .0353$.

These results suggested that hand-held and multifunction key models had the best layouts for key size and spacing. All other sub-sample comparisons of means showed no further significant differences.

Table 4.4

GPS control characteristic ratings

Item	Overall rating (Extremely poor to extremely good)		
	M	*SD*	*n*
Key shape	5.7	1.0	164
Locating keys by day	5.7	1.0	170
Control knobs	5.6	1.2	71
Key pad arrangement	5.5	1.1	162
Key pad feel	5.5	1.1	162
Key size	5.5	1.1	165
Key spacing	5.5	1.2	165
Locating keys at night	5.5	1.4	113
Key coding/symbols	5.4	1.2	165
Cursor operation	5.4	1.1	165

Key dimensions

Table 4.5 lists the key dimensions recorded for the three most popular models in this survey as a comparison against the recommendations of Pheasant, (1988) in Table 1.4. Key diameter was above the minimum and just below the preferred recommendation of 12 to 15 mm. Key travel was below the recommended minimum of 3 mm for each model. Key separation was below the recommended minimum of 6 mm for each model.

Table 4.5

GPS key dimensions.

	Garmin 100	Flightmate	Garmin 55
Diameter or edge length (mm)	10	11	10
Travel (mm)	2	0.5	1
Separation (horizontal)	4	3	3

GPS display design

GPS displays typically present from two to four lines of alphanumeric navigation information at a time with some models able to present a graphical navigation picture referred to as a moving map. Models were grouped into four display types. These are LCD, (e.g. most models in this survey); LED, (e.g. Trimble 2000); vacuum fluorescent, (e.g. Magellan 5000); and CRT, (e.g. King KLN). Table 4.6 shows the frequency of these groupings in the sample. They can also be grouped as moving-map and non-moving map displays. Moving-maps are a relatively new technology and are becoming more popular but were only used by eight percent of the respondents in this survey. Moving maps were not analysed as a sub-sample due to the small sample size with experience in their use.

Table 4.7 shows the respondents' mean overall ratings for GPS display features. Most of the ratings were in the "good" to "very good" range, suggesting that respondents found the displays generally easily readable for the navigation task.

Table 4.6

GPS grouping by display type

Display type	Frequency	Percent
LCD (Liquid Crystal Display)	146	85%
Vacuum fluorescent	13	8%
LED (Light Emitting Diode)	6	3%
CRT (Cathode Ray Tube)	4	2%
Not specified	3	2%
	Total 172	**100.0**

Table 4.7

GPS display characteristic ratings

Item	Overall rating (1 to 7) (Extremely poor to extremely good)		
	M	*SD*	*N*
Display illumination at night	5.8	1.3	117
Display character size	5.5	1.1	172
Display character legibility	5.4	1.1	172
Reading the display in flight	5.2	1.3	172
Display contrast	5.1	1.3	172
Display illumination by day	5.1	1.5	171
Function/mode symbols	5.0	1.2	170
Warning indications	4.8	1.5	164

Table 4.8 compares the mean ratings for each display type. Although the numbers of display types other than the LCD are small, one-way ANOVAs were conducted on the display rating items using the display type sub-group categories (Appendix H5). CRT and fluorescent displays consistently rated best for most items with LEDs the worst rated on each item.

Table 4.8

Comparison between GPS display type ratings

Item	Mean ratings (Extremely poor to extremely good)			
	CRT	Fluor	LCD	LED
Display illumination by day *	7.0	5.8	5.0	4.8
Display illumination at night	7.0	5.5	5.8	5.2
Display contrast *	6.3	6.2	5.0	5.0
Reading the display in flight	6.0	5.9	5.2	4.8
Display character size *	5.8	6.2	5.5	4.3
Display character legibility *	5.8	6.1	5.4	4.3
Function/mode symbols	5.5	5.3	5.0	4.7
Warning indications	5.0	5.2	4.7	4.0

CRT (Cathode Ray Tube), Fluor (Fluorescent), LCD (Liquid Crystal Display), LED (Light Emitting Diode)

* indicates a significant difference between group means ($F(3, 164) > 3.5$, $p < 0.016$) (Appendix H5)

One-way ANOVAs were also conducted on the display rating items using sub-sample categories (Appendix H6).For display contrast, panel-mounts ($M = 5.6$, $SD = 1.1$, $n = 35$) and hand-helds ($M = 5.3$, $SD = 1.3$, $n = 74$), rated significantly higher than portables ($M = 4.7$, $SD = 1.4$, $n = 60$), $F(2, 166) = 7.1$, $p = .0011$.

For daytime illumination, panel-mounts ($M = 5.6$, $SD = 1.4$, $n = 35$) and hand-helds ($M = 5.3$, $SD = 1.3$, $n = 73$) rated significantly higher than portables ($M = 4.5$, $SD = 1.6$, $n = 60$), $F(2, 165) = 7.4$, $p = .0008$.

These results suggested that the portables were not as easy to read during the day with respect to display contrast and illumination. All other sub-sample analyses showed no significant differences.

Power sources

Respondents were asked to rate on a scale of one to seven "never" to "always", what power sources they used for their GPS. Aircraft power was nearly always used (M = 6.2, SD = 1.7, N = 172), with normal batteries (M = 1.8, SD = 1.6, N = 164) or rechargeable batteries (M = 1.7, SD = 1.6, N = 168) as a seldom used backup. Respondents reported that 75% of GPS displays did not indicate which power source was in use.

Design features: Exploratory factor analysis

An exploratory principal components factor analysis with varimax rotation was run to investigate the underlying dimensions of pilots' ratings of GPS design. Three general design factors, two control factors, and two display factors were apparent (Appendix H7). The general design factors were labelled:

1. "In-flight operation" (ruggedness, one-handed operation, flying in turbulence, flying night and day, entering information);
2. "Bulk" (size, shape and weight);
3. "Accessories" (accessories, power sources, antenna connection security);

The control design factors were labelled:

1. "Control dimensions" (Key size, shape, spacing, coding/symbols, location day and night, and control knobs);
2. "Control use" (keypad arrangement, feel, and cursor operation);

The display design factors were labelled:

1. "Display readability" (in-flight readability, display character size, legibility, contrast, illumination day and night);
2. "Display messages" (warning indications, function mode symbols).

Descriptive statistics of these design factors are given in Table 4.9.

Table 4.9

GPS design factor variable ratings

Design Factor	Overall rating (1 to 7) (Low to High)				
	M	*SD*	Min.	Max	*Valid N*
"In-flight operation"	5.5	0.8	3.0	7.0	172
"Bulk"	5.9	1.0	2.0	7.0	172
"Accessories"	5.4	1.1	1.0	7.0	171
"Control dimensions"	5.6	0.9	3.0	7.0	172
"Control use"	5.5	0.9	3.0	7.0	171
"Display readability"	5.3	1.0	2.0	7.0	172
"Display messages"	4.9	1.2	1.0	7.0	170

One-way ANOVAs conducted upon the factors with the four demographic sub-groupings of GPS experience, licence, instructor, and instrument rating revealed only two differences on the "accessories" factor (Appendix H8). When analysed by licence, CPL holders rated "accessories" lower than PPL holders, $F(1, 141) = 4.8$, $p = .0305$; and when analysed by instructor rating, instructors rated "accessories" lower than non-instructors, $F(1, 165) = 4.0$, $p = .0462$. This suggested that the higher trained CPL holders and instructors were more critical of the accessories associated with GPS.

No other significant rating differences between sub-groups were found on the design factors.

Pilots' Attitudes Towards GPS

Confidence in GPS

Table 4.10 shows that overall, respondents were extremely confident with GPS information and when navigating with GPS. They were still confident, but significantly less confident navigating without GPS $t(171) = 8.4$, $p < .001$. Respondents were extremely confident using the basic GPS functions, but significantly less confident using all the GPS functions $t\ (170) = 14.8, p < .001$ (Appendix H9).

Table 4.10

Mean ratings of confidence in GPS

Item How confident are you: -	Overall rating (1 to 7) ("Not at all" to "extremely") *M*	*SD*	*N*
With GPS information	6.2	0.8	172
Navigating with GPS	6.3	0.8	172
Navigating without GPS	5.6	1.2	172
Using basic GPS functions	6.3	0.9	170
Using all the GPS functions	4.6	1.8	170

One-way ANOVAs were conducted on the confidence items (Table 4.10) for demographic sub-groupings (Appendix H10). These revealed seven significant differences on the sub-groupings of GPS experience, licence held, and instrument ratings.

More experienced GPS users had higher ratings for their confidence navigating with GPS, $F(1, 169) = 7.5, p = .0068$; their confidence using the basic GPS functions, $F(1, 169) = 10.6, p = .0014$; and their confidence using all the GPS functions, $F(1, 168) = 18.4, p < .0001$; than less experienced GPS users.

CPL licence holders had higher ratings for their confidence using the basic GPS functions, $F(1, 142) = 4.7, p = .0316$; and their confidence using all the GPS functions, $F(1, 141) = 12.8, p = .0005$; than PPL licence holders.

Pilots holding instrument ratings had higher ratings for their confidence using the basic GPS functions, $F(1, 166) = 8.3, p = .0046$; and their confidence using all the GPS functions, $F(1, 165) = 6.2, p = .0137$; than pilots without instrument ratings.

These results suggested that while there were no significant differences for sub-groups in confidence with the GPS information, more experienced pilots in general had more confidence in their expertise using GPS.

Pilot Attitudes and GPS: Exploratory factor analysis

An exploratory principal components factor analysis with varimax rotation was run to investigate the underlying dimensions of pilots' attitudes towards GPS. Three attitudinal factors were apparent (Appendix H11). These were labelled:

1. "User-confidence" (using all the GPS functions, the user manual, navigating without GPS, and GPS theory knowledge);

2. "Confidence in GPS" (information from GPS and navigating with GPS).

3. "Knowledge required to use GPS".

Descriptive statistics of these attitude factors are provided in Table 4.11.

Table 4.11

GPS attitude factor variable ratings

Attitude Factor	Overall rating (1 to 7) (Low to High)				
	M	*SD*	Min.	Max	*Valid N*
"User confidence"	5.1	1.0	2.0	7.0	172
"Confidence in GPS"	6.3	0.7	4.0	7.0	172
"Knowledge required to use GPS"	4.7	1.3	1.0	7.0	170

One-way ANOVAs conducted upon the attitude factors revealed differences between the pilot demographic sub-groupings of experience, licence, and instrument rating on the attitude factor of "user-confidence" (Appendix H12).

"User-confidence" was lower for less experienced GPS users (100 hours or less)[1] compared with more experienced users (101 hours or more), $F(1, 169) = 10.3$, $p = .0016$; PPL's compared with CPL's, $F(1, 142) = 7.7$, $p = .0061$; and non-instrument

[1] The delineation point of 100 hours for less and more experienced users was chosen as approximately 50% of the sample occurred in each group.

rated pilots compared with instrument rated pilots $F(1, 166) = 7.9$, $p = .0055$. This suggested that less experienced pilots in general had less confidence in their competence using GPS.

Pilots' Behaviour Using GPS

GPS functions

Table 4.12 shows the mean ratings for the frequency with which specific GPS functions were used. It shows that the "go-to direct" and "CDI-bar" features were "often" used, moving map and satellite status were "sometimes" used, and miscellaneous information on airports and communications were "seldom" used.

Table 4.12

GPS feature usage ratings

Item	Overall rating (1 to 7) (Never to always)		
	M	*SD*	*n*
"Go-to direct"	5.7	1.3	165
"CDI-bar"	5.6	1.6	162
"Moving map display"	4.2	2.3	19
"Satellite integrity"	4.0	2.2	162
"Airport information"	2.2	1.7	95
"Communications frequencies"	1.7	1.4	91

Table 4.13 shows the mean ratings for the helpfulness of GPS functions. All GPS functions were rated positively. "Groundspeed", "present position", "distance to go", "go-to direct", "CDI bar", and moving map function's mean ratings were all in the "very good" to "extremely good" range. "Route", "cross-track error", "navigation computer", "nearest search", "database", and "simulator" functions were rated in the "good" to "very good" range. "Alerts" rated least at "so-so" to "good".

Table 4.13

GPS feature helpfulness ratings

Item	Overall rating (1 to 7) (Extremely poor to extremely good)		
	M	*SD*	*n*
"Groundspeed"	6.7	0.6	170
"Present position"	6.7	0.7	170
"Distance to go"	6.7	0.7	170
"Go-to direct"	6.6	0.8	163
"CDI-bar"	6.2	1.2	153
"Moving map"	6.1	1.4	15
"Route"	5.8	1.3	124
"Cross track error"	5.8	1.5	114
"Navigation computer"	5.8	1.1	36
"Nearest search"	5.7	1.5	112
"Database"	5.6	1.4	122
"Simulator"	5.2	1.6	46
"Alerts"	4.5	1.6	96

Data input errors

Respondents were asked to rate on a scale of one to seven ("never" to "always"), how often they had experienced input problems that caused difficulties in flight. "Never" was reported by 45%, "hardly ever" by 34%, while 6% reported that they "often" to "always" had input caused difficulties ($M = 1.9$, SD 1.2, $N = 170$).

Examples of common input errors that were reported by 93 respondents are listed in Table 4.14, while 49 respondents reported not having experienced any input errors. A full listing of mentioned input errors is available in Appendix I.

Table 4.14

Examples of input errors reported by GPS users

- "Co-ordinates in back to front."
- "Either transcription errors from map or transposition of numbers when entering data into GPS."
- "Finger trouble, hitting the wrong key."
- "Forgetting the sequence to obtain the correct information."
- "Inadvertently pressing a key twice in turbulence resulting in a change of mode or number or letter."
- "Incorrect lat. and long. but if you are navigating correctly your map and tracks will show up, also the ADF and VOR will show up your mistakes."
- "Incorrect mode selected i.e. "DCT TO" or "FLTPLAN". Also incorrect "source" selected to autopilot i.e. VOR/ONS/GPS."
- "Inputting aerodrome location instead of say VOR location or NDB which can vary e.g. Wairoa, Kaikoura."
- "Navigating off the wrong GPS waypoint/navaid, bringing up the wrong next waypoint due to poor description of waypoint on display."
- "On Garmin each key has 3 options with L or R to select letter. Sometimes press arrow wrong direction but soon note wrong spelling and so correct - no problem!"
- "Wrong country for the same ICAO designator."

Table 4.15 lists the statements from the nine respondents who reported that an incident had occurred because of input errors.

Table 4.15

Incidents occurring due to input errors

- "Went to wrong airport in the USA."
- "Faulty information from source. Longitude given as east should have been west. Problem glaringly obvious once satellites obtained after take-off."
- "Clipped edge of Christchurch TMA."
- "Inability to locate ground position at night due waypoint entry error."
- "Incorrect coordinates supplied by authorities."
- "On our latest unit there was a database and this got set to some other area The location abbreviations were similar but thousands of miles away."
- "Navigating off the wrong GPS waypoint or nav aid."
- "Gave an incorrect ETA because I had put in an incorrect latitude for a reporting point."
- "Change of Nelson VOR position was not updated. giving conflicting "on track" information. This was not obvious when compared to track and distance of the enroute chart during flight planning data entry."

Misreading errors

Asked what their most common misreading errors were, 90 respondents reported not having any. Examples of misreading errors reported by 37 respondents are listed in Table 4.16. A full listing is available in Appendix I.

Table 4.16

Examples of misreading errors reported by GPS users

- "10 as 18 and vice versa."
- "Wrong CDI bar source (GPS/ONS/VOR)."
- "Becoming oblivious to its persistent warnings (red light on instrument, repeater on panel) particularly when it goes into dead reckoning. If this occurs say on approach or takeoff it retains the wrong info (G/S, track) etc. and until it resumes GPS. I have navigated into the cruise with the wrong information."
- "CDI errors, do not understand function fully."
- "Confusing "track to" to "track made good"."
- "Due to light change due different headings sometimes difficult to read figures due reflection on screen and size of figures."
- "GPS display 000 not 360. This is a very non proactive thing to do. I've never heard of runway 00?"
- I sometimes misread the line because the screen is small and too close to me.
- "Misreading the titles i.e. the small abbreviations e.g. RNG, ETE, DTK. Usually just because I only glanced at it without reading it properly."
- "Swapping between course to steer, course made good, track and not noticing which one I've selected."

Table 4.17 lists the statements from the three respondents who reported that they had experienced incidents through misreading the display.

Table 4.17

Incidents occurring due to misreading errors

- "Infringed Christchurch airspace due to total reliance on GPS heading and not keeping a good lookout."
- "I was flying as non-flying First Officer. The captain hadn't taken his Turn Direction Indicator on his Horizontal Situation Indicator off GPS mode on an Auckland instrument departure. He became disorientated. Very easy to do!"
- "Only once, obvious that "WPT" position was wrong in GPS."

In-flight behaviour

Table 4.18 shows the mean ratings of behaviour changes when using GPS. Workload and map-reading were perceived to have reduced slightly. Frequency of flying, lookout, flying in bad weather, terrain awareness, and distance flown are rated in the "same" to "little more" range. Controlled airspace awareness, situation awareness, track holding, position awareness, and navigation accuracy were perceived to have increased markedly.

Table 4.18

Behaviour changes when using GPS

Item Rate your change in:	Overall rating (1 to 7) (Much less to much more) *M*	 *SD*	 *N*
Workload	2.8	1.4	172
Map and chart reading	3.3	1.2	170
Flight frequency	4.3	0.8	169
Lookout	4.4	1.1	172
Bad weather flying	4.5	1.1	169
Terrain awareness	4.6	1.1	172
Distance flown	4.6	1.6	170
Controlled airspace awareness	5.0	1.2	170
Situation awareness	5.3	1.2	172
Track holding	5.6	1.3	170
Position awareness	5.8	1.3	172
Navigation accuracy	6.0	1.0	172

Table 4.19 shows the mean ratings for GPS helpfulness, for different types of flights. Respondents reported mostly using GPS for VFR cross-country (92%), single pilot (88%), and single engine fixed wing flights (80%). The next most popular use was on multi-crew (40%), IFR cross-country (39%), commercial (39%), and multi-engine fixed wing flights(35%). Respondents reported using GPS the least for helicopter (17%), microlight (4%), military (3%), and glider operations (0.5%). GPS helpfulness was rated

at "very good" to "extremely good" for all these flights. Helpfulness for local area flights (76%), and agricultural flights (8%), was rated at "good" to "very good".

Table 4.19

GPS helpfulness for different types of flights

Item	Overall rating (1 to 7) (Extremely poor to extremely good)		
Type of flight	*M*	*SD*	*n*
VFR cross-country	6.6	0.6	159
Single pilot	6.4	0.8	151
Single-engine fixed wing	6.5	0.6	137
Local area	5.7	1.4	130
Multi-crew	6.4	0.8	69
IFR cross-country	6.6	0.7	67
Commercial	6.5	0.7	67
Multi-engine fixed wing	6.5	0.8	61
Survey Mapping	6.4	0.8	35
Helicopter	6.7	0.7	30
Agricultural	5.3	1.8	13
Microlight	6.6	0.8	7
Military	6.5	0.5	6
Glider	7.0	-	1

GPS as a navigation aid

Respondents were asked to rate on a scale of one to seven "never" to "always", whether they used GPS as a primary or secondary navaid. Overall, GPS was sometimes used as a primary navaid ($M = 4.1$, $SD = 2.3$, $N = 168$). It was "never" used as a primary aid by 27% of respondents, and "always" used as a primary aid by 18% of respondents. GPS was used as a primary aid more often than "sometimes" by 52% of respondents, and less often than "sometimes" by 36% of respondents.

GPS was "often" used as a secondary aid ($M = 5.3$, $SD = 1.9$, $N = 172$), and was "nearly always" used in conjunction with backup methods ($M = 6.1$, $SD = 1.5$, $N = 164$). Backup aids were "always" used with GPS by 58% of respondents, but were "never" used by 4% of respondents.

Using GPS instead of a map or chart

Users responded that 44% "never" used GPS instead of a map or chart, while 24% responded that they "often" (11%), "very often" (9%), or "always" (4%) did. GPS was "always" used by 60% of respondents when they flew. There were no differences between sub-groups on this item.

Monitoring behaviour

Respondents were asked to rate on a scale of one to seven "never" to "always", how often they cross-checked GPS information. Cross-checks were rated as "always" performed by 35% of respondents, and rated as "never" performed by 6% of respondents ($M = 5.3$, $SD = 1.8$, $n = 170$). Comments giving details of the types of cross-checks performed were given by 135 respondents, while 15 respondents reported performing no checks at all. Examples of common checks are set out in Table 4.20. A full listing is available in Appendix I.

Table 4.20

Examples of typical error checks performed by GPS users

- "Against ADF, VOR, DME."
- "Always note track and distance from map and use DR nav to confirm GPS information. Once validated use GPS but maintain DR trackplot."
- "Check for reasonableness from maps etc. Check that planned track and distance are reasonable (Visual flight)."
- "Check number of satellites. Check nav information against other sources."
- "Cross-check GPS to map occasionally but usually rely on GPS as being accurate."
- "Double check entered data."
- "Map reading."

Pilot Behaviours and GPS: Exploratory factor analysis

An exploratory principal components factor analysis with varimax rotation was conducted to investigate the underlying dimensions of pilots' behaviours using GPS. Six behavioural factors were apparent (Appendix H13). These were labelled:

1. "Situation awareness" (navigation accuracy and situational, terrain, controlled airspace, and position awareness);

2. "Workload and map-reading" (workload, map-reading, use of GPS as a back-up aid, not using GPS instead of a map, and not using GPS as a primary aid);

3. "Navigation performance" (bad weather flying and flight frequency, track holding and navigation accuracy);

4. "Cross-checking" (cross-checking, use of GPS as a back-up aid, and back-up methods used with GPS);

5. "Amount of flying" (distance flown, and flight frequency);

6. "Manual reference" (reference to user manual and reduced lookout).

Descriptive statistics of these behaviour factor variables are given in Table 4.21.

Table 4.21

GPS design factor variable ratings

Behaviour Factor	Overall rating (1 to 7) (Low to High)				
	M	*SD*	Min.	Max	*Valid N*
"Situation awareness"	5.4	0.9	1.0	7.0	172
"Workload and map-reading"	3.0	1.1	1.0	7.0	172
"Navigation performance"	5.1	0.8	1.0	7.0	172
"Cross-checking"	5.7	1.3	1.0	7.0	172
"Amount of flying"	4.4	0.8	1.0	7.0	172
"Manual reference"	4.6	1.7	1.0	7.0	172

One-way ANOVAs revealed four differences between pilot demographic sub-groupings for the behaviour factors of "situation awareness", "navigation performance", "cross-checking", and "manual reference" (Appendix H14). "Situation awareness" was rated lower for less experienced GPS users (100 hours or less) compared with more experienced users (101 hours or more), $F(1, 169) = 5.6$, $p = .0191$. This suggested that situation awareness was perceived to have increased as pilots gained more experience with GPS.

"Navigation performance" was rated higher by more experienced users compared to less experienced users, $F(1, 169) = 10.3$, $p = .0016$. This suggested that more experienced pilots were flying in more marginal weather conditions and more often, and that they perceived their navigation and track holding to have improved more than pilots with less GPS experience.

"Cross-checking" was rated to be performed more often by pilots with an instrument rating than by those without an instrument rating, $F(1, 166) = 11.6$, $p = .0008$. This suggested that instrument training gave pilots more options with which to cross-check GPS information.

Less experienced users rated the "manual reference" factor higher than more experienced users, $F(1, 169) = 4.1$, $p = .0437$. This suggested that less experienced users were less proficient with GPS, and that they referred to the GPS manual more often in-flight which appeared linked with a reduction in the amount of time they spent looking outside the cockpit.

Training

Table 4.22 shows the type of training that respondents had, and think is needed for using GPS. Only 11% had some form of training other than reading the user manual and teaching themselves, however 50% believe that some form of training is required. The "other" category included videos.

Table 4.22

Training on GPS

What type of training on GPS -	Did you have? Percent	Is needed? Percent
User manual only	81%	49%
None	8%	1%
Demonstration	8%	13%
Course	2%	26%
Other	1%	11%

Comments expanding on the type of training received were given by 51 respondents. The user manual was used in conjunction with another method by 43 (84%) of these respondents. A demonstration or briefing was received by 22 (43%) of them, generally in an informal manner. Reading the manual and practicing with a GPS unit was regarded as training by 18 (35%) of these respondents. A formal course was taken by six (12%) respondents, a video was used by one (2%) of these respondents, the GPS simulator mode by one (2%) of these respondents, and two (4%) of these respondents reported receiving no training at all (Appendix J).

In contrast, were 118 comments received on the training that was perceived to be needed. A formal course of some description was favoured by 42 (36%) of these respondents, while a demonstration, briefing, or use under instruction was favoured by 39 (33%) of these respondents. Practice in conjunction with using the manual was the choice of 19 (16%) of these respondents, and passing a rating exam was the choice of 12 (10%) of these respondents. Using a video was the choice of three (3%) of these respondents, the GPS simulator function was the choice of two (2%) of these respondents, and one (1%) of these respondents did not want to see any training until GPS was approved for instrument flight when he wanted a formal exam as part of the instrument rating test (Appendix J).

A subtly different question asking what training users would like to see available received comments from 138 users. Of these respondents, 68 (49%) would like a formal course to be available, 26 (19%) would like a demonstration or briefing, 12 (9%) would like an exam as part of the navigation syllabus, 11 (8%) didn't want any training available, 16 (12%) would like a video, five (4%) would like a good user manual, two (1%) would like a simulator, and one (1%) would like hands on practice.

Reference to the user manual and user knowledge

The user manual was always referred to by 13% of respondents, with 5% never referring to it, the mean being just above "sometimes" (*M* = 4.6, *SD* = 1.7, *N* = 172). The mean rating for manual ease of use, was just above "so-so", with 36% of respondents rating it easy to use, and 9% rating it difficult (M = 4.7, *SD* = 1.6, *N* = 170).

The mean self rating for user knowledge of GPS theory, was just under "good" (M = 4.8, *SD* = 1.3, *n* = 172). The mean rating for the level of knowledge needed to operate GPS, was similar (M = 4.7, *SD* = 1.3, *N* = 170).

Flight Safety

Users were asked if they had any examples of flight safety hazards or traps that may catch people out using GPS. The responses have been grouped into categories. User comments are listed in Appendix K. Overall, possible hazards were mentioned by 133 respondents in the following areas.

Four users believed that a lack of competence and user knowledge about their GPS equipment could cause problems if flight conditions changed and routes needed to be re-programmed or if operators were not using backup methods of navigation.

Data input, output, monitoring, and checking hazards were listed by 58 respondents. These included inputting incorrect position coordinates (rubbish in, rubbish out); failing to cross-check GPS information especially against charts; fixating on GPS rather than looking out; infringing airspace or terrain clearance by using the "GOTO direct" function without checking the flight path, misreading displays; lack of "mode awareness" such as the CDI scale setting, flying true versus magnetic track, bearing "from" instead of "to", or continuing on an incorrect route leg; not realising when GPS accuracy is degraded due to poor satellite reception and continuing on "dead reckoning"; lack of ability to check route structures with flight plans (nor suggestions to do so in the manuals); using outdated databases when information has changed; neglecting to have backups in the case of GPS failure; and not monitoring the system closely when connected to aircraft automatic systems such as autopilots and Horizontal Situation Indicators (HSI's).

Lookout, scan, and terrain hazards listed by 19 respondents indicated possible problems in these areas. It was mentioned by 12 users that it was easy to be distracted by the display and to neglect to keep a proper scan and lookout especially when still unfamiliar with the use of GPS. Many also felt that VFR pilots using the "direct-to" function could forget to check charts for the terrain height ahead. Situation awareness, and judgement hazards and traps were listed by 35 respondents. Possible hazards included over-dependence on GPS information without checking it; not being aware of a map position should GPS information be lost; becoming overconfident and flying in weather conditions they wouldn't without GPS; flying VFR above total cloud cover and losing GPS or not being able to find a cloud break; tempting non-instrument rated pilots beyond their trained ability; losing basic navigation skills through disuse and complacency; overconfidence; not using maps and charts; using GPS altitude; and violating controlled airspace.

Power, reception, and physical hazards and traps were listed by 12 respondents. Most are current problems such as power or reception failures at critical times with no warning, and cables interfering in the cockpit. Other hazards suggested included electronic interference with other equipment; having information corrupted when entering data if the batteries are low; disorientation looking at the display when on the yoke or off centre positions; trusting electronic moving map displays; and a danger of traffic congestion at popular waypoints as more VFR pilots fly on standard routes extremely accurately using GPS.

Difficulties using GPS

Users were asked what they found difficult about using GPS and what problems they had experienced. They were also asked how these problems could possibly be avoided. The responses have been grouped into categories. User comments are listed in Appendix K. Overall, some difficulties with GPS were mentioned by 120 respondents including learning how to use it, using the manual, using the controls, reading the displays, operating the complex functions, physically positioning the GPS in the cockpit, maintaining the power supply, using the database, non-standardisation, and in-flight operation. No difficulties or problems using GPS were reported by 52 respondents, although seven of these stated that this was after they had learnt how to operate the unit and had plenty of practice with it.

Learning, knowledge, practice, and user manual problems were reported by 34 users. Comments included problems learning to use the units which were felt could have been helped with a better knowledge of GPS operating principles and limitations; more time practicing before trying to use GPS (not all units offer a simulator mode for non-flying practice); better user manuals; receiving training such as courses, demonstrations, or videos; and more intuitive operating logic for the "average" pilot. Difficulty learning to use GPS was reported by 20 respondents. Difficulties raised included following the user manual, remembering the different functions and input sequences, lack of computer literacy, a lack of theoretical knowledge of GPS, and lack of practice. The need to use GPS often to remember how to operate the various features correctly was mentioned by 18 respondents. Poorly written user manuals that were hard to follow were mentioned by seven respondents. Difficulties were expressed with the computer jargon used, and the general layout.

Problems with using the controls were reported by 11 users. These included too many keys, not enough separate keys for the functions, too much key pushing required, small key size, narrow keypad spacing, deep-nested multi-level menu searching, and difficult data entry in flight, especially in turbulence.

Visual display difficulties were reported by 12 respondents. All complained of readability problems in certain light conditions especially bright sunlight, and with the display window dimensions and character size for readability. Some complaints concerned the way in which navigation information was presented. Some GPS display a track of due North as 000° instead of 360°, and the presentation of three-figure groups beginning with 0, (e.g. 010°) as two-figure groups (e.g. 10°) was confusing. Some models display odd and even altitudes to fly, based on track directions that are incorrect for New Zealand airspace rules. Some models do not display information in ICAO units (used in New Zealand) (e.g. hectopascals instead of inches of barometric pressure). Warning tones can be difficult to hear or be confused with aircraft system warnings such as an undercarriage unsafe condition in Piper Arrow aircraft.

Difficulties with GPS functions and complexity were mentioned by 42 respondents. Many complained that there were too many functions, that some were obscure, and that programming was time consuming. Many felt that the systems were complex and that this caused difficulties remembering how to operate the systems. Many users felt that there was excess information available that was not useful and that interfered with information access. It was considered that multiple function keys required too much key pushing to access information. "Finger" problems with data input and the need to cross-check data entry was emphasised. It was noted that most GPS models do not encourage, or in some cases allow checking of route track and distances, making it difficult to identify data entry errors.

The cost of regular database updates was mentioned. The inability to limit access to particular database regions such as Australasia was frustrating as the international database on most models is huge and selection of a New Zealand waypoint designator may involve scrolling through the many navigation aids from around the world before finding the appropriate one. Airports with runways shorter than 2000 feet were often not in the database.

One user mentioned the problem of trying to mount the unit in a good position in a full instrument panel. This was seen as a problem with "add-ons" which can be expensive to fit if re-positioning other instruments. Yoke mountings were mentioned to be time consuming to fit and remove and they took the position normally given to holding instrument approach plates for IFR flights. Difficulties were expressed about including the display in the instrument scan and manipulating the controls due to the GPS position, especially for two pilot operations.

Power supply problems were reported by 14 users. All mentioned the problem of battery power running out because of the inherently high usage (at a greater rate than advertised by manufacturers); or the unit losing aircraft power through poor connections and not warning of this possibility. Users reported that low battery warnings come only moments before operation was curtailed. Some solutions offered were to have a battery life remaining indicator such as found on mobile telephones; to have an indicator showing if the unit is running on internal or external power; to carry plenty of spare batteries; and to have automatic switching to batteries if aircraft power is lost (which some did models offer). Rechargeable batteries last much less time than alkaline batteries but the high usage of batteries becomes expensive very quickly. There was no display indication of battery condition on any model surveyed.

Aerial and satellite reception problems were reported by 41 users. Some reported that they originally had problems with a lack of available satellites but that this now seemed rectified with the full constellation in place. Most problems with losing coverage were a result of the aerial position or connection. All users reported that optimum system performance was obtained with external aerials. Although windscreen "sucker" mounted aerials offered improved reception over internal aerials, the extension cables caused problems trailing around the cockpit and could be a flight hazard. Portable extension aerials were reported to be easy to dislodge. One user reported satellite degradation coinciding with air strikes in Bosnia that put them 5.5 km from their expected position.

Users commented that it was difficult not to be distracted and spend time looking at the display at the expense of their lookout, or to start depending on GPS as it appeared to be extremely accurate and reliable. They commented that when waypoints were occasionally entered incorrectly and not picked up, then they were accurately guided to where they had not intended to go.

Users also commented that they found non-standardisation between units difficult when using different GPS models with different controls and operating logic, especially for route programming.

CHAPTER 5

DISCUSSION

This study investigated GPS equipment design, and GA pilots' attitudes and behaviours when using GPS. The findings have implications for training and flight safety. The five research questions (see Chapter One, page 45) are now discussed. In addition, suggestions for appropriate training to operate GPS are given. Limitations of this research and suggestions for further research are also noted.

GPS Design Features And Human Factors Principles

The first research question asked whether GPS design features were in accordance with established human factors principles. The results found that GPS design was rated extremely positively by users who appeared to minimise the design faults that were evident. Instead, users focused on the general ease of operation and high level of accuracy and reliability that GPS offered for navigation. The pilot's ratings of GPS design altered little for any of the demographic sub-sample comparisons that were conducted, including pilots' age, experience, licence, instructor and instrument rating qualifications. The pilot's ratings of GPS design were also consistent between model, control, display, and mounting category.

General principles

All GPS units surveyed had an obvious and accessible On/Off switch, which is a basic requirement for usability (Norman, 1988). All hand-held units required the Off switch to be held down for a number of seconds with a displayed warning before switching off to prevent accidentally turning off the system. All indicated that power was on but not necessarily the power source, which meant occasionally flattening the batteries of hand-held models when operators erroneously believed the system to be securely connected to the aircraft power supply. This violated the principle of visibility (Norman, 1988).

In terms of navigation operations, the principle of visibility was not always followed either. Some relationships between the controls and their functions were unclear creating problems of "mode awareness" (Hawkins, 1987). Some of the information displayed was similar in different operating modes and it was possible to become confused between selected modes. The functions grouped under the various modes differed between models and did not always appear logical or intuitive to the user, indicating that the designers' conceptual model at times appeared disparate to the pilot's mental model. The more complex functions were found to be difficult to learn and to maintain proficiency in operating without regular practice. Heavy demands were made upon the user's memory at times as not all the procedures were clearly indicated by "knowledge in the world" (Norman, 1988) gained by viewing the receiver. For example, "present position" was found in an accessories page in one hand-held model, rather than in the navigation page.

Standardisation

GPS units from four manufacturers comprising 17 different models were represented in this survey. Pronounced differences between individual models and model groupings were apparent. A lack of standardisation existed on each dimension of GPS design including size and shape, instrument mounting method, control type and layout, display size and composition, information displayed, and operating logic. Users did not rate any particular design dimension as superior. Difficulties were identified in relation to the lack of standardisation which resulted in system training problems and confusion when operating between different units.

For hand-held models, the main choice existed between alphanumeric and function key, or multifunction key control layouts. Multi-function keys controlled a menu driven display in contrast to entering information with the alphanumeric and function keys. Multi-function keys were rated higher for layout. By definition, a "better" layout reduces the potential for input errors (Oborne, 1987). However, research does not appear to exist to quantify the optimum layout for GPS controls. An experimental comparison of control types could be made to assess any difference in data inputting accuracy and ease of use overall, including learning and remembering the associated operating logics.

Panel-mounted systems typically used a combination of function keys and knobs. These systems tended to be more complex and were more likely to be used for IFR operations. The operating logic of using function keys to select menu areas, and knobs to scroll the menus and select the information before using a key to enter it, was typically the most complicated system. These systems appeared to require a greater amount of memory and attention to operate the deeper nested functions available. These systems also appeared to be less intuitive to use and were reported to require significant training to acquire proficiency.

Reception

The portable GPS receivers used had certain operational limitations. They required a remote antenna for optimum reception. Most hand-held models surveyed had a suction cup accessory to secure the detachable antenna to the windscreen. Extension cables were required to connect these to the receiver, and these could be dislodged or interfere with other flying operations. Large manoeuvres could cause brief shadowing of the signal to an internal antenna resulting in a temporary loss of GPS information. Some users reported that aircraft with a permanently mounted GPS antenna installed on top of the aircraft alleviated this problem.

The mounting of hand-helds and portables in the confined space of the cockpit could be a problem. It was positive to find that most users secured the equipment by some means rather than leaving it insecure to become a possible safety hazard in turbulence or abnormal manoeuvres. While some users found a yoke mount to be beneficial for in-flight security, control access and display legibility, others found that these mounts obscured other instrumentation and caused them to look down to read the display rather than looking up to maintain a good lookout. Difficulty with the optimum positioning of an add-on device such as this was reported in the limited confines of the cockpit.

Power

Portable GPS receivers were generally powered by an AA battery pack, or by rechargeable NiCad packs. Connection to the aircraft powered cigarette lighter was an optional accessory which was the most preferred option for users. Hand-held battery usage was often higher than advertised and flat batteries were reported to arise at inopportune moments with little warning. Panel-mounted receivers were permanently mounted in the instrument panel and were connected to aircraft power and an external antenna. This avoided the trailing wires or awkward mounts associated with hand-helds. Some solutions offered for power supply integrity were to have an external battery life remaining indicator such as found on mobile telephones; to indicate whether the unit was running on internal or external power; to carry sufficient spare batteries; and to have automatic switching to batteries if aircraft power was lost, which some models did offer. Power supply and aerial reception problems were reported to be a likely cause for the loss of GPS information.

Positioning

The majority of users preferred their GPS to be positioned high and central in the instrument panel which is in accord with the human factors principles of visibility and access (Sanders & McCormick, 1992) from both pilot positions. However, the size of the relatively small displays with primary symbol heights in the order of 4-5 mm, and secondary symbols only 2-3 mm high, made them difficult to read at times over the typical viewing distance from the pilot's seat to the instrument panel.

Controls

GPS controls were rated overall as adequate. Key size and spacing was constrained by the small size of the unit. Hand-helds and portables were small and light-weight to ensure easy portability, whilst panel-mounts were typically designed to fit into the standard relatively small "nav/comm." space in the instrument panel. It appeared that the driving force in dimension design was for the equipment to be able to fit into an existing radio stack, rather than for human factors principles of operation determining the size of the displays and controls. For example, in some cases keyboard dimensions were less than published guidelines (Pheasant, 1988; Department of Defense, 1989).

The complexity of the units was relatively high with each control generally operating several different functions. Some users complained of the arbitrary relationships that this created, making learning and remembering lesser used functions difficult. Some units violated Norman's (1988) principle of visibility with the state of the device not always being readily apparent at a glance from the displays. The estimated accuracy of the GPS calculated position being one example on some receivers.

In general, the response compatibility between controls and displays followed natural mapping principles (Norman, 1988), with good and appropriate feedback on the screen with a highlighted cursor to indicate the system state.

Displays

The "good" to "very good" ratings given to displays indicated that users found them adequate for the task, but that there was room for improvement. The comments that were made amplified this conclusion, with all displays having readability problems at times. Display readability suffered from the small unit size making the display screen alphanumerics difficult to read under certain ambient lighting conditions. The majority of the displays surveyed were LCD and a conclusive comparison of the ratings between the four display types was not possible. Controlled experimental research could be useful here to determine the optimum display type for readability under standard in-flight conditions. CRT and fluorescent displays tended to rate best for illumination, contrast and legibility. Likewise, there were few displays surveyed incorporating a moving map and further research to consider specific aspects for these would also be useful.

Warnings

The warning features of the displays were not highly rated by the users. It was mentioned that warning messages sometimes went unnoticed, and that when they were observed they were often distracting. GPS units typically displayed a flashing message light which required the pilot to access the message page to read the warning and to cancel the message light. There was no immediate indication of the importance of the warning, and it was reported to be often only advisory and unimportant. This was a further violation of the principle of visibility (Norman, 1988).

According to human factors principles warnings need to be attention grabbers (Hawkins, 1987). They need to perform their alerting function without being startling, and a major problem for designers is determining what problems are critical and warrant alerting the pilot. A second warning function is to report the nature of the problem under alert. Thirdly, warnings should provide a guide for the appropriate corrective actions.

Important failure warnings should involve an auditory warning as the pilot needs to directly view a visual warning to perceive it. Flashing lights can go unnoticed more often than buzzers or bells (Hawkins, 1987). It appeared that while most GPS units had a warning tone associated with every message alert, the volume was often insufficient to be audible above the ambient cockpit noise.

It is important that the warning systems are valid and reliable, sounding only for genuine problems. Early Ground Proximity Warning Systems (GPWS) were prone to giving false readings, and this could have caused pilots to ignore genuine ones (O'Hare & Roscoe, 1990). A further problem is that there can be too many message alerts, which may become an irritation, creating extra workload. Pilots may end up ignoring an important message due to the lack of distinction between them. This is a possibility with the typical GPS warning system surveyed.

Design dimensions

Pilots' ratings of GPS design reduced into seven factors when an exploratory factor analysis was conducted. Three factors emerged for general design. GPS was viewed in terms of its "bulk", "in-flight operation", and "accessories". The first general design factor of "bulk" had a mean rating as "very good" indicating that the size, weight and shape of GPS was perceived to be well designed within the context of its use, whether hand-held, portable or panel-mounted. Users appeared to be satisfied with the physical dimensions of the equipment.

The second general design factor of "in-flight operation" had a mean rating between "good" and "very good" overall which again indicated a good design with few problems performing the primary GPS functions to users' satisfaction in standard flying conditions.

The third general design factor of "accessories", while still receiving a "good" to "very good" mean rating, attracted more comments indicating some areas of dissatisfaction. Primarily, these applied to hand-held and portable models which required attachments to enhance the power supply and satellite signal reception, and to locate the unit within the cockpit using various mounting devices. The necessity for trailing wires with the greater probability of a GPS signal interruption with these units was mostly due to the removable nature of these systems. They appeared to be designed primarily for VFR flight and operation at various times in different aircraft. These problems were mostly absent in the permanently installed panel-mounted models. "Accessories" was the only factor to show a significant rating difference between user sub-groups with CPL holders and instructors rating them lower than PPL holders and non-instructors. This possibly reflected higher experience in this group and a greater awareness of flight hazards with the trailing wires, potentially unreliable power supply and the reduced reception associated with some GPS accessories.

The design ratings for GPS controls reduced into the two factors of "control dimensions" and "control layout". The means of both factors were rated "good" to "very good" and again indicated user satisfaction to achieve the navigation task. Areas for design improvement were apparent. Control dimensions could be made larger, with increased spacing between keys to improve data entry. Some user comments indicated that improvements to the layout, dimensions, and coding of the keys could reduce the input errors that were reported to regularly occur. The guidelines from Pheasant (1988), the Society of Automotive Engineers (1988a), and the U.S. Department of Defense (1989) may assist here.

The design ratings for GPS displays reduced into the two factors of "display readability" and "display messages". While the mean for "display readability" rated as "good" to "very good", comments from users indicated that the display size and presentation required improvement to reduce the display reading errors reported to occur. Users noted that larger displays with improved screen resolution, that were easier to read in all lighting conditions would make overall readability greater. The guidelines from the Society of Automotive Engineers (1969, 1988a, & 1988b) may again assist here.

The factor of "display messages" included both visual and aural warnings, and function mode symbols on the screen. This factor received the lowest mean rating at "good". This suggested that the mode symbols could be enhanced on the display to clearly indicate the mode in operation, thereby reducing the opportunity for "mode errors" (Hawkins, 1987) to occur and improving feedback and visibility (Norman, 1988). Warning messages should to be improved to reduce unimportant distractions, and to make critical warnings attention getting (Hawkins, 1987; O'Hare & Roscoe, 1990).

GA Pilots' Attitudes Towards GPS

The second research question examined pilot's attitudes towards GPS. The results found that the navigation functions offered to pilots by GPS received extremely high ratings. Features such as accurate groundspeed, distance to go, and course deviation indications made their task much easier than was previously the case. The perceived precision and reliability of GPS gave the users great confidence in the GPS information. This was reflected in the results that respondents used GPS most of the time when flying, and that they were significantly less confident navigating without it. They were also significantly less confident using the more complex GPS functions such as route creation, possibly because these required a greater depth of knowledge, and practice to remember. Most keys controlled several functions because of space constraints and this made the use of GPS complicated for more than the basic functions. Thought needs to be made in the design process for more intuitive steps to easily access the required information. This suggested an area of practical operation of GPS that required training, as the deeper levels were not as intuitive and user-friendly to operate as the basic levels on most models.

Attitude dimensions

Pilot's attitude ratings reduced into three factors when an exploratory factor analysis was conducted. These were "user confidence" (expertise), "confidence in GPS", and "knowledge required to use GPS". It appeared that "user confidence" and "confidence in GPS" were unrelated. This suggested that the user's confidence in the displayed GPS information and navigating with GPS, was distinct from the user's confidence in their theoretical knowledge of GPS operation and their ability to competently use the GPS equipment and user manual.

Users rated their mean confidence in the displayed GPS information at 6.3 on the 7-point scale, while their confidence in their ability to understand and use GPS was rated at 5.1.

Pilots with the greater experience levels associated with more than 100 hours using GPS, and holding a CPL and instrument rating; were significantly more confident in their ability to operate GPS than those with 100 hours or less using GPS, holding a PPL, and with no instrument rating. There was however, no difference between users on the factor of "confidence in GPS". This suggested that while some pilots may not be as confident in their ability to operate GPS to its potential, they may still trust it to take them to their destination and depend on it to do so. This group may have been less likely to monitor the GPS and therefore realise when the information was no longer valid, with potentially dangerous consequences. This group may have also been less likely to have expertise with traditional cross-country navigation methods and it was possible that with GPS they were flying beyond the point that they would fly without it. It was also possible that this group was less able to apply reversionary procedures if they lost GPS information. This conclusion was reinforced with comments made by respondents indicating that they had been tempted to fly in conditions that they would not have contemplated without GPS being available.

In this regard, these results may indicate that GPS is an example of automation in the cockpit that is encouraging some operators to place excessive trust in the automated system (Wiener & Curry, 1980). GPS may also be encouraging attitudes such as "automation-induced complacency" (Parasuraman et al., 1993), over-reliance and over-confidence. Training that raises the awareness of this "complacency potential" (Parasuraman et al., 1993) may help to guard against these attitudes occurring.

The users' knowledge-base about GPS operation has the potential for considerable improvement. Users mean rating for their knowledge of GPS theory was "good", as distinct from "very good" or "excellent". It is possible that training courses would increase the rated level of knowledge perceived as necessary to operate GPS proficiently. It may be that while a "good" knowledge is rated as needed to operate GPS in a basic manner, a far greater level of knowledge of both theoretical and practical aspects of operation is required to use GPS to its maximum capabilities, and to avoid the operational and human factors pitfalls identified in the study.

GA Pilots Behaviour Using GPS

The third research question asked how GA pilots behaved using GPS. The results showed how pilots typically used their GPS operationally, and which GPS information was deemed the most useful. The results also showed that there were some examples of behaviours that may be viewed as inappropriate to the continued safety of operations using GPS.

GPS functions

There appeared to be a need to standardise the availability and labelling of the GPS navigation functions. The pilots' ratings of the usefulness of the different functions may be related to how often they accessed them, however the order in which the functions were presented differed between models. Navigation functions often appeared across more than one navigation display "page" due to the limited space available for information on the display screen. It seems logical to have the most useful and important information available on the primary navigation page. While most GPS receivers allowed individuals to customise the navigation display pages to some degree, it was still possible to have more useful information available on a secondary page, or to have extraneous information cluttering the primary page. This appears to be an example of the designer's conceptual model differing from that of the user (Norman, 1988).

Terminology also varied between various models, for example, "direct-to", and "go-to" were descriptions for identical operations by different GPS models. It may be that research is required to determine the optimum function labelling before standards can be applied (Landy, 1989).

The results showed that the "go-to direct" and "CDI-bar" were the most frequently used functions (Table 4.12). These were easily accessible on most models surveyed, and some users reported only using these features to navigate with.

Users reported hardly ever using GPS to access database information such as radio frequencies and airport information (Table 4.12) that could be found elsewhere in printed flight publications. This may be related to the novelty of having such information available electronically. Accessing this information through GPS was a complicated procedure and users may not have had the time, expertise, or desire to obtain it through the database. Additionally, there is a relatively substantial cost to maintaining the currency of the GPS database. It may have been that many users were not keeping their databases up to date, and so were instead referring to current printed information. This may become an important safety issue when using GPS for Primary Means IFR operations, when it will be mandatory to operate with a current database installed.

The navigation functions were all rated positively for helpfulness (Table 4.13), but while some were rated only at "good", four were at the extreme positive end of the scale indicating that they were highly valued and used a great deal. These were the "groundspeed", "present position", "distance to go", and "go-to direct" functions. These results suggested that the first three information functions should be available on the primary navigation page, along with the "CDI-bar" which also rated very highly. The "go-to direct" and "moving map" functions required their own pages, but should be quick and easy to access through a dedicated control function key. The "route" and "navigation computer" functions were rated as very helpful and were possibly rated lower due to the extra effort required to learn and operate them. The "simulator" function available on some models received a "good" rating. This is possibly more helpful for less experienced users still learning the system.

"Alerts" were rated just above "so-so" and this is may be due to the difficulty seeing and hearing them in flight, coupled with the distraction of having to attend to flashing message symbols, accessing the message page, reading the "alert" message, and returning to the navigation page each time. This result suggested that GPS "alerts" may require research to determine how to make them more attention grabbing if critical, and less distracting if unimportant.

In-flight behaviour

The majority of respondents used GPS for single-engine single pilot VFR cross-country flights. Multi-engine, multi-crew IFR cross-country flights were the next major grouping. In general, the former flights used hand-helds and portables, while the latter used portables and panel-mounts. GPS was rated as very helpful for all the flights in which it was used. The survey was conducted at a time when GPS was beginning to become popular and readily available to pilots, and when approval to fly with it was relatively new. As time passes it is likely that most pilots will begin to routinely operate with GPS. Certainly the proportion of flights using GPS as the primary method for navigation is expected to increase rapidly. This survey showed that GPS was already routinely being used in most GA flight environments.

At the time of the survey, GPS was only approved as a supplemental aid to navigation, however 73% of respondents reported sometimes using it as a primary aid. While certain GPS units will soon be approved for Primary Means navigation, these results showed that pilots were already depending on GPS as their primary reference. Moreover, a small percentage of pilots appeared to use GPS as their sole navigation means. The high accuracy and reliability of GPS and users' demonstrated confidence in its information are likely to increase this percentage over time. The importance of planned redundancy in the event of GPS operational limitations to prevent complacency and over-reliance on this single navigation method cannot be over emphasised.

Operating errors

Input errors and misreading errors occurred when using GPS. This was mainly due to the small dimensions of the controls and the small display screen. Incidents due to such errors were reported. Although the number of users reporting difficulties here were small the safety implications may be considerable. Fortunately, nearly half the respondents reported never having made an input error. Those pilots who had made errors reported that they normally picked them up quickly through cross-checking procedures. This may be due to pilots remaining more in the control loop with a relatively low workload (Wickens & Kessel, 1981). Moreover, it appeared that the incidents that were reported to have resulted from input and misreading errors were likely to have been avoided if standard cross-checking procedures had been used.

Cross-checking

A concern from the results was that nearly six percent of users did not cross-check the GPS information, and that a further quarter of pilots were at times flying using GPS instead of a map. This over-reliance on the equipment could have fatal consequences if the route data has been entered incorrectly. Incorrect route data entry was reported, although most times it was corrected through cross-checking. An allied concern raised by the study was that the design of many GPS units made it difficult to easily check the entered track and distances of routes with the flight plan. This is a basic requirement for safe navigation to prevent the machine "dumbly and dutifully" taking the operator to where it has been programmed but not intended to go. This was a poor design feature of many models. Thorough pre-flight checking of the route track and distances in the GPS against the flight plan is essential to minimise the chances of data entry errors resulting in diversion from the planned route in-flight. Such activity requires an amount of self-discipline by the operator and this requirement should be emphasised in training for GPS.

Risk taking

Users reported being tempted to fly in conditions they would not consider without GPS. This was reflected in the rating of slightly more frequent bad weather flying. Other similar risk behaviours reported by a small proportion of GPS users included flying above cloud without an instrument rating which has grave safety implications, especially if the pilot loses GPS information which can occur for a variety reasons.

Workload

Wiener (1988) noted that a principle rationale for automation may be questionable. This is the rationale that automation requires less manual handling and mental computation, which in the case of flying should leave the pilot free for more effective supervision. Wiener suggested that while manual workloads have reduced with automation, mental workloads have increased, as have the range of skills required of pilots to operate sophisticated automated equipment. He states that new aircraft technology requires more programming, planning, sequencing, alternative selection, and cognitive processing on the part of the pilot.

The results suggested that GPS had slightly reduced the pilots' perceived overall workload (Table 4.18), possibly due to a reduced requirement to read maps and make mental navigation computations. This suggested that training should emphasise that pilots should not reduce their workload by relying entirely on GPS for position guidance thereby neglecting to cross-check GPS with maps and charts.

Lookout

Wiener (1988) stated that a second rationale for automation may also be questionable. This is the rationale that automation allows more time to be available to pilots, that could be utilised for the important activity of looking out of the cockpit and scanning for other aircraft. Instead Wiener believed that pilots perceived automatic devices to require constant attention and that therefore the time needed to scan the displays reduced the time available to scan outside the cockpit. This study found that pilots using GPS rated their lookout to have increased slightly (Table 4.18). This may be due to the time taken scanning the unit making up for less time spent reading charts. GPS did not however, appear to be encouraging more time looking inside the cockpit at the expense of looking outside.

Tracking

GA pilots using GPS reported to be much more accurate with their navigation and tracking, and to be more situationally aware of their position relative to airspace and terrain (Table 4.18). Although the models surveyed did not display terrain information, and few showed controlled airspace boundaries, it was likely that the GPS gave users a precise position with which to locate themselves on a map to reveal the relevant airspace and terrain. This is a very positive feature for using GPS and it should reduce the number of pilots becoming lost or using extra fuel through poor route following. However, pilots may require specific training to emphasise that GPS does not directly provide terrain information, nor an accurate height above ground which GPS calculates with reference to a mathematical model of the earth (Hofmann-Wellenhof et al., 1992). GPS must be used in conjunction with maps to cross-check the track made good by the aircraft against terrain and airspace restrictions. The increased accuracy of flying direct tracks VFR between popular waypoints raises the issue of "unofficial VFR routes" being created. This may have the effect of "funnelling" VFR traffic closer together putting pressure on the concept of "see and be seen" for VFR separation.

Behaviour dimensions

Pilot's behaviours reduced into six factors when an exploratory factor analysis was conducted. These were "situation awareness", "workload and map-reading", "navigation performance", "cross-checking", "amount of flying" and "manual reference". Three of these factors showed statistically significant differences between demographic sub-groups. These were "situation awareness" with experience, "navigation performance" with experience, and "cross-checking" with instrument rating.

While "situation awareness" was rated to have increased markedly using GPS (Table 4.21), it increased significantly greater for the more experienced users. This suggested that pilots were developing new skills in conjunction with using GPS over time. This appears to indicate that GPS has assisted pilots to navigate with greater accuracy and awareness.

"Navigation performance" was associated with increased bad weather flying and track holding, and increased navigation accuracy and flight frequency. More experienced users rated higher on this factor compared to less experienced users. This possibly indicated that as pilots' proficiency and confidence in their ability to maintain track using GPS grew, so to did the frequency with which they flew in more marginal weather conditions. The study showed that flying in bad weather using GPS only increased slightly. This factor indicated that it was more likely to be by pilots with over 100 hours experience using GPS, who perceived that their navigation accuracy and track holding was markedly improved. This suggested that a calculated risk-taking behaviour may have been occurring with some pilots.

"Cross-checking" of GPS with other navigation sources was more likely to be carried out by pilots with an instrument rating than without and this suggested a greater opportunity, training, and expertise to compare other navigation aids to GPS for these pilots. This may indicate that the discipline of training associated with an instrument rating instils useful equipment-monitoring habits This has training implications for pilots flying Primary Means GPS IFR. Moreover, this may be linked to research indicating that the most important element determining greater monitoring performance is practice (Moray, 1986).

"Workload and map-reading" was the only behaviour factor to be rated to have reduced to "a little less" overall. This indicated that navigation with GPS was less demanding and that GPS had reduced the time previously spent mentally computing and referring to charts. This ought to allow some additional pilot resources to be devoted to other tasks such as lookout and scanning.

"Amount of flying" was reported to have increased slightly. This suggested that GPS did not appear to have encouraged either longer distance or more frequent flights. It was possible that the slight increase was due to additional flying in marginal weather conditions that pilots were only attempting when using GPS.

"Manual reference" was associated with reduced lookout. This was rated between "sometimes" to "often" for all pilots indicating that even experienced users needed to refresh their memory on the operating instructions at times. This reinforces comments that although GPS appears to be easy to operate, this relates to the basic functions, and training and practice is required to use it expertly to its full capacity. Additionally, less experienced users rated higher on this factor, suggesting that they were referring to the manual more often in flight and that this was reducing the time they spent looking out of the aircraft. This implies that better GPS training could increase the time available for lookout by reducing the amount of time spent referring to the manual in flight.

Training Requirements For GA Pilots To Safely Use GPS

The fourth research question asked what training was required for GA pilots to safely use GPS. Currently, GA pilots are required to train for and to hold an instrument rating to fly by reference to navigation instruments under IFR, however GPS is available for supplemental IFR use without formal training (Civil Aviation Authority, 1995b), and for use by non-instrument rated pilots in visual flight.

The results showed that little formal training was available for GPS. Typically, pilots were left to teach themselves using the manual, or else they obtained informal demonstrations from other experienced users. Over a third of respondents considered that a formal training course was required to enable proficient use of GPS, and over half the respondents indicated that they would attend such a training course if it was available. As the majority of respondents in this survey were VFR pilots, suitable training may possibly be perceived as even more important for IFR operations with GPS. An analysis of the knowledge needed to operate GPS safely and proficiently, coupled with a consideration of the human factors learning requirements, may help determine the level of training needed.

A training course should be an effective means for alerting pilots to the difficulties that may be encountered using GPS, and presenting strategies to deal with these. The avoidance of common data input errors through standardised cross-checking procedures can be taught before users discover that their checking procedures were inadequate. Training guidelines for automated aviation systems indicate that extensive training to develop a full understanding of the benefits and possible failures that may occur with automation are required (Wiener & Curry 1980).

Training must emphasise the need for close monitoring of GPS like any other automated equipment and for the comparison of GPS data with other navigational sources. GPS without built in integrity-monitoring such as RAIM (Random Autonomous Integrity Monitoring) does not necessarily indicate when the position information is invalid (Civil Aviation Safety Authority, 1995). It is possible that the average VFR pilot will not have the instrument monitoring experience required to realise the importance and difficulty involved in the checking task. Users need to be made aware of the various reasons for GPS information failure and encouraged to question the validity of the data. A naive perception was that the major danger in trusting GPS is that the satellites may be turned off by the U.S. Department of Defense without notice. It was far more likely however, that the batteries would go flat or that the operator would program the GPS incorrectly, as evidenced by the results.

Training should indicate the appropriate use for maps and charts in conjunction with GPS. Correct methods of flight planning and checking, monitoring progress with regard to airspace and terrain, and reversionary procedures should be considered.

While GPS equipment is generally well designed and easy to operate, there were complex features that required practice to master, and there are ways to use it that invite disaster should things go wrong. By instilling a level of over-confidence in the ability to navigate under any situation, inappropriate decisions may be made to fly in unsuitable conditions should GPS information fail for any reason. Pilots need to be aware of such situations, of the likelihood and causes for losing GPS information, and of the means to ensure that they get the maximum benefit from their high-technology machine. Training that promotes standardised operating procedures for VFR and IFR flight with GPS, and that alerts users to possible problems and how to avoid them, is a necessary step to ensuring flight safety is only improved with the further implementation of GPS.

The survey identified a number of human factors issues with flight safety implications related to inadequate training. Human factors training to raise operator awareness of possible hazards when operating GPS in an inappropriate manner is needed to standardise operational practices and to minimise the dangers associated with a lack of knowledge in specific areas. Some of the issues identified here included operator complacency, over-reliance, risk taking, and a lack of basic navigation monitoring techniques. While respondents showed that they were extremely confident with the information they receive and the reliability of GPS, there was a worrying indication that this included aspects of overconfidence, and that precautions were not always being taken in the event that GPS information became unavailable. The self-reports indicating that respondents were significantly less confident navigating without GPS, and in using the more complex functions available, suggested that GPS may have been encouraging basic "pre-automation" skill levels to decline without full proficiency with the equipment being attained.

It should be noted however, that many learning difficulties identified by the survey such as the computer jargon and concepts used by GPS, poorly written user manuals, and a steep learning curve, can be overcome primarily by better designed equipment and well written operating manuals. An appropriate training course should then be in addition to these, rather than a replacement for their inadequacies.

Learning considerations for GPS training

"Knowledge that" is knowledge of facts, principles, relations, or what has been described as declarative knowledge. This is contrasted with "knowledge how" which is how to do something such as fly a plane or program a GPS. Researchers in human thought processes have found the distinction useful in modeling learning and performance phenomena (Anderson, 1976). Thus procedural memory is memory for production knowledge, or "knowledge how", just as declarative memory is memory for declarative knowledge or "knowledge that". Procedural and declarative memories are both a type of long term memory characterised by slow decay over time. It is convenient to represent procedural or production knowledge in terms of "If-then" or condition-action rules called productions.

Compared to learning in declarative memory, relatively little research has been conducted on how learning new productions occurs. It is likely that there are some differences between the two kinds of learning. New facts can be learned simply by being told them. On the other hand, learning new procedures or new rules may depend largely on practice (Schneider, 1985). The more practice, the better will be the exercise of various kinds of cognitive and motor skills. This may be important when learning to operate systems such as GPS.

Research into production learning suggests that what comes about as a result of increased practice is the capability for more carefully determined selections of which specific productions to apply in a given instance. Thus, early stages of skill development may be characterised by frequent errors in applying productions, and later stages by few errors: that is; by knowing which situation calls for which technique (Kyllonen & Alluisi, 1987).

Memory association

Learning can be thought of as a three-stage process of encoding, storage, and retrieval. Encoding refers to the process of extracting the essential information from some input. Storage refers to the process of forming a copy of the symbol set in declarative memory, so that it can be retrieved at a later time. Considerable attention has been given to how people remember and represent the associations among various concepts. One of the key ideas to emerge from the literature (Anderson, 1976; 1983; Anderson & Bower, 1973; Norman & Rumelhart, 1975) is that humans are adept at remembering the meaning of some input string (such as a sentence), even though some of the surface features (such as its syntax) may be quickly forgotten. It would appear that being "wired for meaning" is a fairly reliable and distinctive feature of memory that aids retrieval. The meaning of scenes viewed, and utterances heard, are retained long after the surface features of those incoming experiences are lost (e.g. Bransford & Franks, 1971).

A higher-order representation exists besides concepts and propositions however. For example, everyone has a great deal of knowledge of various mundane events such as doing the dishes, or writing a letter (Bower, Black & Turner, 1979). This knowledge facilitates communication because it allows the recipient to infer many of the events that occur even when not explicitly stated. The memory units that enable inferences of this type have been called scripts (Schank & Abelson, 1977), schemata (Rumelhart & Ortony, 1977), and frames (Minsky, 1975).

Two of the most important properties of such memory structures are that they allow property inheritance and include default values (Bower, Black & Turner, 1979). Property inheritance refers to a memory unit inheriting a property from a higher-order memory unit. For example, when told that an instruction manual has been written for a GPS, it can be readily inferred what the instruction manual is like without knowing what a GPS is. If it is known that a GPS is some kind of electronic navigation device, certain general attributes of such a device may be assumed. Default values refer to the fact that certain aspects of a situation can be inferred without being explained specifically. It may be assumed for example, that a GPS has some method for data entry and some type of navigation information display. It may also be assumed with less confidence, that the data entry method is some sort of keypad, that the unit is made of plastic, and that it has an electric power supply. Although these assumptions are made with limited confidence, they make communication and learning easier by inferring that they are true until told otherwise. The advantage of having such complex and well-organised representations is that they serve as shorthand expressions for a complex set of characteristics. The disadvantage is that they frequently lead to expectations and assumptions about items and events that are not valid. For example, once one GPS model's operation has been learnt, a pilot is likely to expect another to be similar when it is not. Thus, the pilot may get caught out attempting to achieve a task with a system that is not operating as expected due to a non-standard operating logic.

Context

Research has shown that learners' recall is best when the test conditions most closely represent those under which the materials were originally learned (Tulving, 1983). This phenomenon has been referred to by Tulving as the encoding-specificity principle. Although there are exceptions to this principle, the effect has occurred in a sufficiently wide variety of contexts to be regarded as fairly robust. Thus, learning to use GPS while flying as a passenger is likely to allow better recall of the control functions than attempting to learn the theory of its use in the classroom. Physically operating a GPS to perform worked examples in the classroom may be an equally valid method of learning. Similarly, the availability of "simulator "functions on some models may encourage effective learning by mimicking real flight experiences without actually travelling (Wiener & Nagel, 1988).

Motivation

An important determinant of learning success would seem to be motivation. Surprisingly, laboratory studies have shown the intention to learn (one form of motivation) does not directly affect learning success (Kyllonen & Alluisi, 1987). Instead, the amount of processing of the input stimulus is more directly related to the probability of the stimulus being remembered. The data suggests that it is not enough to merely want to learn something, but that it is more important that learners know how to study and implement this knowledge (Kyllonen & Alluisi, 1987).

Intentional motivation to learn affects whether a stimulus is attended to in the first instance and whether the subject will persist in trying alternative methods for studying or diagnosing. Successful performers tend to try different approaches until they find one that works. Unsuccessful performers tend to give up more easily and more quickly (Kyllonen & Alluisi, 1987).

The most important motivational consideration for many applications is determining how the learning task can be made more motivating rather than determining who is motivated. Interest, for example, tends to be a powerful predictor of what will be remembered, and interesting learning materials are motivating. Anderson (1983) estimated that in normal text; subjective ratings of interest were thirty times more important than readability in predicting recall.

Instructional programmes can be designed to include many of the motivating features of video games that are known to strongly encourage learning (Malone, 1981). These might include explicit goals, using sound effects, having an element of randomness, employing graphics rather than words to convey instructions and feedback, and keeping score. This suggests that a useful adjunct to classroom-based training courses may be multi-media computer based GPS training programs that can incorporate such elements. These programs can also successfully simulate problem solving situations for the in-flight environment, in addition to allowing the student to absorb the information at their own pace.

Developing a GPS training course

On the basis of this study a training course was developed in Australia for pilots using GPS as Primary Means IFR navigation. The course consisted of sections on GPS theory, system components, principles of operation; navigation performance requirements; authorisation and documentation; errors and limitations; human factors of operation; and specific GPS navigation procedures and equipment checks.

The key findings from this study of the human factors problems that existed with the use of GPS were incorporated into the course. The human factors section was written by the author to incorporate ergonomics of design, such as standardisation, controls and displays, and physical location; GPS operation; operational behaviour such as input errors, workload, mode awareness, monitoring, and cross-checking; hazardous attitudes such as over-reliance, complacency, over-confidence, and distraction; and specific model proficiency requirements. This information was incorporated into a booklet to complement the course (Civil Aviation Safety Authority, 1995).

Flight Safety Hazards Associated With GA Pilots Use Of GPS

The fifth research question asked whether there were any flight safety hazards associated with GA pilots use of GPS. The study suggested that the appropriate use of GPS had encouraged safer flying by significantly improving pilots' navigation performance while slightly reducing their workload and increasing their lookout on cross-country VFR and IFR flights. While small design faults existed that contributed to input and misreading errors occurring, these were generally rectified through monitoring and cross-checking procedures by most pilots. The greatest design flaws that could lead to accidents were the lack of route checking ability, and absence of battery condition indicators on some models.

The major hazards associated with using GPS were found to be the attitudes developed by some users in response to the perceived accuracy and reliability of the machine. Inappropriate faith in the machine led to some pilots flying in conditions that were difficult for them when GPS information was lost. Little understanding of the limitations associated with GPS through insufficient training, and the image of GPS as an infallible piece of automation may be contributing to the attitudes identified that could lead to accidents. These were over-reliance on the machine without suitable reversionary procedures to hand, over-confidence in the availability, reliability and validity of the GPS information, over-confidence in their own ability to navigate without needing to cross-check GPS, and complacency, which also led to neglecting monitoring and standard checking procedures.

A graphic example of such attitudes and behaviours was reported to the author and confirmed with the air traffic controller involved (A. Isaac, Massey University, personal communication August, 1994). A pilot flight planned VFR from Auckland to Tauranga, was queried by Auckland Radar Control when it appeared that he was flying on the Rotorua track. The pilot who besides this cue from the radar operator should have been confirming his track visually from a map, replied that he was definitely on track as he was "centred on his GPS CDI-bar". It was not until this pilot actually arrived overhead Rotorua that he admitted his error but he then blamed a previous pilot for incorrectly programming the GPS! Such was this individual's reliance and confidence in the GPS information presented to him, and the lack of cross-checking the GPS track against the flight plan and actual ground track in flight.

The ease of making a small error when inputting waypoint information is a hazard when the programmed route that the GPS is following is not diligently checked. The GPS was often inadvertently programmed to track elsewhere to that intended. This is the same category of hazard that was a factor in the crash of Air New Zealand into Mt. Erebus (Vette, 1983) as GPS does not display the terrain ahead of the aircraft.

Implications Of This Research

The implications from this research are that future GPS receivers should incorporate design changes to improve their operation from a user-centred perspective. Physical improvements following published guidelines could be made to the controls and displays, the power supplies, and the antenna connections. Control dimensions and layout should be increased to reduce the potential for keying data entry errors. Display panel dimensions should be increased, with larger symbols and icons to improve readability. All hand-helds should display the battery condition and power source at a glance to give a continuous indication to the pilot of how long the power in use will be available.

Improvements could also be made to the system operating logic. Standardisation should be implemented between models. It should be a straight forward operation to check each leg of the programmed GPS route track and distance against the flight-planned route, to reduce the chances of critical data input errors. All models should display navigation information in a recognised standard format. For example, tracking information should be in a three-figure group from 001 degrees to 360 degrees, and tracking information such as 070° should not be displayed as 70°. Display modes should be readily apparent to the user at all times to reduce mode confusion errors. Message "alerts" should be improved to reduce the distraction that they can offer. Critical warnings should be more evident to the operator. Considerations should be made for designers to incorporate features to reduce the trust (Wickens, 1984) that operators have in the machine to prevent over-confidence, reliance, and complacency.

The content, layout and indexing of GPS operating manuals should be generally improved. Manuals could possibly be presented as coherent instructional packages. Other complimentary instructional packages such as computer-based training programs could be offered to novice GPS operators. Formalised training is required for operators to gain the knowledge and expertise necessary to use the system to its full potential and to avoid errors made through ignorance of system limitations. Training is also required to raise operators awareness of the human factors issues involved.

A major implication from this study of pilots using GPS for VFR and supplemental IFR flights is that the problems identified are potentially greater for the future use of GPS as a Primary Means and Sole Means IFR enroute and approach navigation aid. This implies that more research is needed in this area to assess the flight safety ramifications involved.

Longer term, the effect upon pilots' ability to effectively monitor and cross-check GPS performance when current ground based navigation aids are withdrawn from service as planned (Civil Aviation Safety Authority, 1995) will also need to be examined.

Limitations Of This Research

The main limitation of this research was its exploratory nature. The study was reliant on respondents' ratings of their attitudes and behaviours when using GPS equipment. This approach was valuable to obtain a picture of GPS users that was previously only conjecture, but it only enabled initial trends to be identified. Conclusive evaluation of pilots behaviours can only occur through observation in simulated and actual flight operations. Nether the less, this study has provided a reasonably comprehensive review of many of the aspects associated with GA pilots use of GPS. While some GPS model and demographic sub-groupings were too small to enable statistically significant comparisons to be drawn, the overall sample size was large and sufficiently diverse for reasonable generalisations of the findings to be made to the current user population.

Suggestions For Further Research

This study suggested areas meriting future detailed experimental investigation. These are detailed below.

1. An evaluation of the optimum control design for accuracy and ease of use of hand-helds and panel-mounted units. For hand-helds, a bench test comparison for ease of

learning and operation of alphanumeric versus multifunction keys and their associated operating logics. For TSO C-129 (Federal Aviation Administration, 1992) rated approach panel-mounted equipment, a thorough bench-test evaluation of the controls is required.

2. An evaluation of the units for optimum display readability, for both standard and moving map displays. This should include an evaluation of optimum information presentation, and screen size.

3. An investigation into the relationship between confidence with GPS and inappropriate flying behaviours such as lack of cross-checking and monitoring, and flying beyond the pilot's level of skill and experience.

4. An evaluation through in-flight observations of actual monitoring, cross-checking, and tracking behaviour using GPS.

5. An investigation is required into the workload demands that using GPS for instrument approaches will place upon pilots. This is a markedly different and more demanding situation than the type of flying investigated in this study and the complexity of operating GPS for this task is far greater. A human factors analysis of the approaches themselves and their presentation to the pilots should be conducted in conjunction with such a study. A method employing both objective and subjective measures as used in a recent study into pilot workload while conducting various instrument approaches (Wiggins, Wilks, & Nendick, 1996) could be well utilised in such a study.

Conclusion

This study has evaluated GPS design, and examined the way in which GA pilots used GPS, from a fundamental psychological and human factors perspective. The aim was to identify human factors problems requiring redress, and to designate specific issues requiring further experimental research. An additional aim was to identify training requirements for the safe use of GPS by GA pilots, and to encourage the development of such training. The study achieved its aims to obtain quantifiable empirical data as a basis for further experimental analysis of pilot interaction with this system. The survey identified aspects of design that could be improved upon, and it determined how GPS design has affected pilots' rated attitudes and behaviours when navigating with GPS. The study has also been used as a basis for developing a training course for GA pilots.

In general, the results found that GPS is relatively well designed and it is rated highly on most counts by all users, independent of any demographic grouping tested, including flying experience, experience with GPS, licence held, instrument rating, or instructor rating. The most salient finding here was that GPS appeared to affect the majority of pilots in a very similar fashion, irrespective of their individual demographics. This implied that the results were generalisable to all flying operations using GPS and that training to raise pilot awareness of human factors issues can be applied on a broad basis without being targeted to particular groups.

While various features of GPS design were identified that could be improved upon, the study showed that GPS is perceived by its users to be very well designed for its intended task. In fact, it appears that GPS may be perceived to be better designed than evaluation suggests is actually the case, and that the extremely positive ratings may indicate more subtle human factors issues. These are that users' enthusiasm for the abilities of GPS have developed attitudes leading to over-confidence, reliance, and complacency. This may have resulted in some examples of inappropriate behaviours such as operating without backup means, discarding standard navigation procedures such as maintaining reference to maps and charts, and navigating with GPS before gaining an acceptable level of knowledge and competency with its use. The GPS feature of operational simplicity as perceived by users according to Clarke (1994) may be a subtle trap. GPS certainly was easy to operate on a basic and superficial level with minimal training and experience, but it required a significant amount of knowledge and practice to operate correctly on a deeper level for more complicated navigational tasks. This will be an important consideration for GPS as Primary Means navigation in contrast to its use as a supplemental aid in this study. Users who think they can do anything with GPS without a thorough understanding of its capabilities and limitations are likely to get themselves into strife and incidents have been reported for precisely these reasons.

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Appendix A: Definitions Of Abbreviations

ADF	Automatic Direction Finder
3D	Three dimensional
CDI	Course direction indicator
CRT	Cathode ray tube
EL	Electroluminescent
ETA	Estimated time of arrival
ETE	Estimated time enroute
FLUOR	Fluorescent display
GA	General Aviation
GPS	Global positioning system
HSI	Horizontal Situation Indicator
IC's	Integrated circuits
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
LCD	Liquid crystal display
LED	Light-emitting diode
Mmap	Moving map
ONS	Omega navigation system
Primary Means Navigation System	A navigation system that, for a given operation or phase of flight, must meet accuracy and integrity requirements, but need not meet full availability and continuity of service requirements.
RAIM	Receiver Autonomous Integrity Monitoring
Satnav	Satellite navigation
Sole Means Navigation System	A navigation system that, for a given phase of flight, must allow the aircraft to meet all four navigation system performance requirements - accuracy, integrity, availability and continuity of service.
Supplemental Means Navigation System	A navigation system that must be used in conjunction with a sole means navigation system.
TMA	Terminal Area
VFR	Visual Flight Rules
VOR	Very High Frequency Omni-directional Range nav aid

Appendix B: GPS User Survey

1. How many months have you been using GPS? ______

2. How many days per month do you use GPS on average? __________

3. What makes and models of GPS have you used? ____

   ____

4. What makes and models of GPS have you owned? ____

   ____

5. Do you have any preferences between models of GPS? Yes ☐ No ☐

   If yes, please specify ____

   ____

6. What is the main make and model GPS that you use? ________________________________

   (Please specify both make and model)

Please refer to the GPS in Question 6 when answering the rest of the survey.

7. Overall, how easy is the GPS to use?

   not at all 1 2 3 4 5 6 7 extremely

Design

For any question that does not apply , please tick the NA box.

Give your overall rating of the GPS for:

8. Unit size and shape

   extremely poor 1 2 3 4 5 6 7 extremely good

9. Unit weight **extremely poor 1 2 3 4 5 6 7 extremely good**

10. Antenna connection security

    extremely poor 1 2 3 4 5 6 7 extremely good

11. Power sources

    extremely poor 1 2 3 4 5 6 7 extremely good

Give your overall rating of the GPS for:

12. Accessories **extremely poor** 1 2 3 4 5 6 7 **extremely good**

13. Ruggedness **extremely poor** 1 2 3 4 5 6 7 **extremely good**

14. One-handed operation (hand-held)

    extremely poor 1 2 3 4 5 6 7 **extremely good NA** ☐

15. Flying in turbulence

    extremely poor 1 2 3 4 5 6 7 **extremely good**

16. Flying by day **extremely poor** 1 2 3 4 5 6 7 **extremely good**

17. Flying at night

    extremely poor 1 2 3 4 5 6 7 **extremely good NA** ☐

18. Entering information

    extremely poor 1 2 3 4 5 6 7 **extremely good**

Controls

Give your overall rating of the GPS for:

19. Key pad arrangement

    extremely poor 1 2 3 4 5 6 7 **extremely good**

20. Key pad feel **extremely poor** 1 2 3 4 5 6 7 **extremely good**

21. Key size **extremely poor** 1 2 3 4 5 6 7 **extremely good**

22. Key shape **extremely poor** 1 2 3 4 5 6 7 **extremely good**

23. Key spacing **extremely poor** 1 2 3 4 5 6 7 **extremely good**

24. Key coding/symbols

    extremely poor 1 2 3 4 5 6 7 **extremely good**

Give your overall rating of the GPS for:

25. Locating the keys by day

extremely poor 1 2 3 4 5 6 7 **extremely good**

26. Locating the keys at night

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

27. Control knobs

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

28. Cursor operation **extremely poor** 1 2 3 4 5 6 7 **extremely good**

Displays

Give your overall rating of the GPS for:

29. Reading the display in flight

extremely poor 1 2 3 4 5 6 7 **extremely good**

30. Display character size

extremely poor 1 2 3 4 5 6 7 **extremely good**

31. Display character legibility

extremely poor 1 2 3 4 5 6 7 **extremely good**

32. Display contrast **extremely poor** 1 2 3 4 5 6 7 **extremely good**

33. Display illumination by day

extremely poor 1 2 3 4 5 6 7 **extremely good**

34. Display illumination at night

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

35 Warning indications

extremely poor 1 2 3 4 5 6 7 **extremely good**

36. Function/mode symbols

extremely poor 1 2 3 4 5 6 7 **extremely good**

How helpful do you find the GPS for the following types of flights?

(If you do not fly the type of flight specified using GPS please tick the NA box)

37. Single-engine fixed-wing flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

38. Multi-engine fixed wing flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

39. Helicopter flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

40. Glider flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

41. Microlight flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

42. Single-pilot flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

43. Multi-crew flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

44. Local area flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

45. VFR cross-country flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

46. IFR cross-country flights

    extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

How helpful do you find the GPS for the following types of flights?

47. Survey mapping flights

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

48. Agricultural flights

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

49. Military flights

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

50. Commercial flights

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

51. Other types of flights

extremely poor 1 2 3 4 5 6 7 **extremely good** **NA** ☐

(specify) ____

Functions

If you have not used the function, answer 'do not use', or 'never'.

If the GPS does not have the function referred to, answer 'not applicable' (NA).

52. How helpful do you find the simulator function?

extremely poor 1 2 3 4 5 6 7 **extremely good** **do not use** ☐ **NA** ☐

53. How helpful do you find the E6B/flight computer function?

extremely poor 1 2 3 4 5 6 7 **extremely good** **do not use** ☐ **NA** ☐

54. How helpful do you find the moving map display?

extremely poor 1 2 3 4 5 6 7 **extremely good** **do not use** ☐ **NA** ☐

55. Do you use the moving map display to navigate with?

never 1 2 3 4 5 6 7 always NA ☐

56. How helpful do you find the GPS database?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

57. How helpful do you find the "Go-to" direct function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

58. Do you use the "Go-to" direct function to navigate with?

never 1 2 3 4 5 6 7 always NA ☐

59. How helpful do you find the Route function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

60. How helpful do you find the alarm functions?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

61. How helpful do you find the "nearest airport/nav aid" search function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

62. How helpful do you find the ground speed function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

63. How helpful do you find the cross track error function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

64. How helpful do you find the CDI-bar function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

65. Do you use the GPS CDI display to navigate with?

never 1 2 3 4 5 6 7 always NA ☐

66. How helpful do you find the distance to go function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

67. How helpful do you find the present position function?

extremely poor 1 2 3 4 5 6 7 extremely good do not use ☐ NA ☐

68. Do you use the satellite information functions to check the GPS information?

never 1 2 3 4 5 6 7 always NA ☐

69. Do you obtain comms frequencies from the GPS?

never 1 2 3 4 5 6 7 always NA ☐

70. Do you obtain airport information from the GPS?

never 1 2 3 4 5 6 7 always NA ☐

71. Do you use the GPS instead of a map or chart?

never 1 2 3 4 5 6 7 always

72. What are the main modes and functions you use on the GPS for flight planning?

____

____

73. What are the main modes and functions you use on the GPS in flight?

____

74. If the GPS has yoke mounting available, how often is the GPS yoke mounted when you fly?

never 1 2 3 4 5 6 7 always NA ☐

75. If you use both handheld and yoke mounted, which do you prefer and why? __________________

____

76. Where would you prefer the GPS to be positioned and why? ____________________________

____

When you fly with the GPS, how often is it:

77. In use? **never** 1 2 3 4 5 6 7 **always**

78. Run off normal batteries? **never** 1 2 3 4 5 6 7 **always**

79. Run off rechargeable batteries? **never** 1 2 3 4 5 6 7 **always**

80. Run off aircraft power? **never** 1 2 3 4 5 6 7 **always**

81. Does the display indicate which power source is in use? Yes ☐ No ☐

82. What type of backup power does the GPS have? ______________________________

83. How often do you cross check GPS information?

never 1 2 3 4 5 6 7 **always**

84. How often do you have input errors that cause difficulties in flight?

never 1 2 3 4 5 6 7 **always**

85. Have any incidents occurred because of these input errors? Yes ☐ No ☐

If yes, please specify ______________________________

____

____

86. What error checks do you perform? ______________________________

____

____

87. What are your most common input errors? ______________________________

____

____

88. What are your most common misreading errors? ______________________________

____

____

89. Have any incidents occurred because of misreading the GPS? Yes ☐ No ☐

If yes, please specify ____

____

____

Compare the way you fly using GPS, with the way you flew before you used GPS, for the following questions:

90. Rate the change in your workload

much less 1 2 3 4 5 6 7 **much more**

91. Rate the change in your map and chart reading frequency

much less 1 2 3 4 5 6 7 **much more**

92. Rate the change in your lookout

much less 1 2 3 4 5 6 7 **much more**

93. Rate the change in your position awareness

much less 1 2 3 4 5 6 7 **much more**

94. Rate the change in your controlled airspace awareness

much less 1 2 3 4 5 6 7 **much more**

95. Rate the change in your terrain awareness

much less 1 2 3 4 5 6 7 **much more**

96. Rate the change in your situation awareness

much less 1 2 3 4 5 6 7 **much more**

97. Rate the change in your distance flown

much less 1 2 3 4 5 6 7 **much more**

98. Rate the change in your flight frequency

much less 1 2 3 4 5 6 7 **much more**

99. Rate the change in your track holding

much less 1 2 3 4 5 6 7 **much more**

100. Rate the change in your navigation accuracy

much less 1 2 3 4 5 6 7 **much more**

101. Rate the change in your bad weather flying

much less 1 2 3 4 5 6 7 **much more**

General

102. Do you use GPS as a primary navigation aid?

never 1 2 3 4 5 6 7 **always**

103. Do you use GPS as a backup navigation aid?

never 1 2 3 4 5 6 7 **always**

104. Do you have backup methods/aids when navigating with GPS?

never 1 2 3 4 5 6 7 **always**

105. What methods/aids do you typically use to navigate on VFR cross country flights?

DR ☐, ADF ☐, VOR ☐, DME ☐, GPS ☐, INS ☐, ONS ☐, Track crawl ☐,

Map reading ☐,Other ☐ (Specify) ______________________________

106. What methods/aids do you typically use to navigate on IFR cross country flights?

DR ☐, ADF ☐, VOR ☐, DME ☐, GPS ☐, INS ☐, ONS ☐, Track crawl ☐,

Map reading ☐,Other ☐ (Specify) ______________________________

107. How confident are you with the information the GPS provides?

not at all 1 2 3 4 5 6 7 **extremely**

108. How confident are you navigating with GPS?

not at all 1 2 3 4 5 6 7 **extremely**

109. How confident are you navigating without GPS?

not at all 1 2 3 4 5 6 7 **extremely**

110. What training did you have on the GPS? User manual ☐, None ☐

Other (Specify) ____________________

111. What training do you think is needed on the GPS? User manual ☐, None ☐,

Other (Specify) ____________________

112. What training would you like to see available for GPS? ____________________

____

113. Do you refer to the user manual? **never** 1 2 3 4 5 6 7 **always**

114. How easy is the manual to use?

not at all 1 2 3 4 5 6 7 **extremely**

115. How confident are you using the basic GPS functions?

not at all 1 2 3 4 5 6 7 **extremely**

116. How confident are you using all the GPS functions?

not at all 1 2 3 4 5 6 7 **extremely**

117. Rate your knowledge of GPS theory

extremely poor 1 2 3 4 5 6 7 **extremely good**

118. Rate the level of knowledge needed to operate GPS proficiently

extremely poor 1 2 3 4 5 6 7 **extremely good**

119. What do you find difficult about using the GPS? ____________________

____

____

____

____

120. What problems have you had using the GPS? ______________________________

____

____

121. How could these problems be avoided? ______________________________

____

____

122. Do you have any examples of hazards or traps that may catch people out using GPS?

____

____

____

123. Do you have any views on how GPS should be developed for use in NZ? (e.g. as a primary navigation aid)______________________________

____

____

124. Are there any changes or additions you would like incorporated into flight publications, maps or charts, that would help when using GPS? ______________________________

____

____

125. Do you have any other comments that were not covered in the survey? ______________

____

____

____

____

____

____

Biographical details

Age (to whole year) _______ Male/Female _______

Flight Licences: PPL ☐, CPL ☐, SCPL ☐, ATPL ☐,

Other ☐, (Specify) ______

Ratings: Instrument _____ Instructor(Cat) ______ Ag ________

Other (Specify) ______

Hours Flown (to nearest 10)

Grand total flight hours __________

Total Instrument time __________

Total hours using GPS __________

Total hours in last 12 months __________

Total hours in last 12 months using GPS __________

Contact Details (Optional) (These details are confidential and will be accessible only by the researcher for follow up purposes - you will be allocated a unique code number to ensure that confidentiality is maintained)

Name: ______________________________

Address: ______________________________

______________________________ Phone (bus) ________

______________________________ Phone (a/h) ________

______________________________ FAX ________

On receipt of the completed survey your name will be entered into a draw to win one of 25 one-year subscriptions to Wings magazine donated by NZ Wings.

Winners will be notified by mail.

Please indicate with a tick if you would like:

- to be notified of the survey results ☐
- to take part in a future study of GPS use ☐

Thank you for completing this survey.

Please return as soon as possible (envelope supplied) to:

Mike Nendick
GPS Survey
Psychology Department
Massey University
FREEPOST 86
PALMERSTON NORTH

Appendix C: GPS Survey Information Sheet

GPS USER SURVEY INFORMATION SHEET

Dear GPS user,

This survey is part of a research study into the use of Global Positioning Systems (GPS) by NZ pilots, being conducted by Mike Nendick under the supervision of Dr. Ross St. George, at Massey University. The researcher is a navigator and pilot currently completing a Masters degree incorporating Aviation Psychology.

The study is examining Human Factors aspects of GPS use in NZ. Some of the issues under investigation are: What type of GPS are most commonly in use? How are they being used? What advantages and disadvantages do operators find with them? How easy are the controls and displays to operate? Does their use change the way pilots navigate around the country? What are pilot's attitudes towards using GPS as a primary navigation aid?

Your reply will help gain understanding of GPS use in NZ and may lead to improvements in GPS design, training, and use. The survey results will be available to interested participants and relevant details will be published to ensure the maximum use of the results.

Participation in this study is voluntary and all information will be treated in strictest confidence by the researcher. Your response details will be coded so that no information received can be linked back to you. Your name and contact details will only be known to the researcher and these will be separated from your reply. It is assumed that by filling in this survey the participant consents to taking part in the research.

If you own or operate a GPS as a pilot please take the time to answer this survey and return it in the envelope provided as soon as possible to:

Mike Nendick
GPS Survey
Psychology Department
Massey University
FREEPOST 86
PALMERSTON NORTH

Your participation in this study is greatly appreciated. Further information is available from Mike Nendick c/ of the above address or telephone 06-354-6397. If you know other pilots that use GPS please inform them of this survey. Further questionnaires can be obtained from the freepost address.

Thank you for agreeing to participate in this survey.

Mike Nendick

Instructions

Please tick the appropriate boxes, circle the appropriate numbers, or fill in the spaces as required (write NA for non-applicable items).

If you wish to write extra comments on using GPS you are welcome to enclose extra pages with the completed survey.

Most questions can be completed by filling in one of the answer choices. If you do not find the exact answer that fits your case, use the one that is closest to it. Try to avoid neutral answers if possible.

Expanded scale examples

never 1 2 3 4 5 6 7 always
never sometimes always

extremely poor 1 2 3 4 5 6 7 extremely good
extremely poor so-so extremely good

much less 1 2 3 4 5 6 7 much more
much less same much more

not at all 1 2 3 4 5 6 7 extremely
not at all so-so extremely

Please detach this page and use it to refer to as you complete the survey.

Appendix D: GPS Survey Critique Sheet

Dear

Thank you for trialing this questionnaire. All constructive comments are welcomed. This includes the format, length, question style, clarity, ambiguousness, and so on. Please answer the questionnaire in blue ink. Write comments where appropriate next to each question in red ink. Write additional and overall comments on page 2 of this sheet.

How long did it take to complete? ___ Is the survey a reasonable length? ____

The following is a checklist of points to look for when assessing the questionnaire. These are guidelines only. Don't feel you have to check off each point.

Is the introduction

clear
concise
understandable
explanatory
interesting

Are the instructions

clear
understandable

Are any questions:

unclear
confusing
ambiguous
leading (i.e. suggest answers)
offensive
threatening
relevant
boring
assuming too much
requiring too much memory

Is the layout:

clear
adequate in space for answers
easy to complete

Are the scales

clear and meaningful
are the response options mutually exclusive and sufficient to cover each conceivable answer?

Please write additional and overall comments on this sheet.

Appendix E: GPS Survey Advertisement Card

ATTENTION - GPS USERS!

Have you used GPS? There is a nationwide survey being conducted on GPS use in New Zealand.

Your reply will help gain an understanding of GPS use by pilots in NZ and may lead to improvements in GPS design, training, and use.

If you have used a GPS and are interested in participating in a survey investigating aspects of GPS use by pilots in New Zealand,

Please fill out your Contact Details and Return this Form to the Freepost Address (over).

You will be sent a survey to complete. All participants will have the survey results available to them and participant confidentiality is assured. The survey is being conducted by Mike Nendick under the supervision of Dr. Ross St. George (both GA pilots), as part of a Massey University research study. It should take approximately 35 minutes to complete.

This survey is being supported by Airways Corporation of New Zealand Limited and New Zealand Wings.

I have used GPS and would like to participate in the GPS survey. Please send me the survey to complete.

Name ______________________________

Address ______________________________

____

____

PTO

POST
PAID

FREEPOST 86
Mike Nendick
GPS Survey
Psychology Department
Massey University
Private Bag 11-222
PALMERSTON NORTH

______________(Fold here and seal)______________

Appendix F: GPS Survey Reminder Letter

Freepost 86
Mike Nendick
GPS Survey
Psychology Department
Massey University
PALMERSTON NORTH

14 September 1994

GPS User Survey

Dear

This is a reminder to please complete and return your survey form if you have not already done so. I have had a very positive response to the survey so far and I am beginning data analysis so prompt returns are appreciated.

If you have lost your survey please send to the freepost address for another. If you have already sent your survey back, please disregard this reminder. Thanks again for your participation in this research.

Yours sincerely

Mike Nendick.

Appendix G User Comments On The Physical Mounting Of GPS

If you use both handheld and yoke mounted, which do you prefer and why?

Yoke

- Yoke because I don't need to use both hands to work with it.
- Yoke because it fits between handgrips on yoke controls.
- Yoke better position.
- Yoke is best!
- Yoke it is permanently displayed in front of you at a comfortable readable distance.
- Yoke its got its place in the aircraft.
- Yoke mount always readable at a glance.
- Yoke mount for single pilot op.
- Yoke mount, better positioned for ease of use.
- Yoke mount- hands free.
- Yoke mount. Leaves hands free.
- Yoke mounted - doesn't get in the way.
- Yoke mounted - frees hands for other functions.
- Yoke mounted - you need 2 hands otherwise.
- Yoke mounted fixed position easy eye contact. Near to hand.
- Yoke mounted in flight only.
- Yoke mounted is convenient to read.
- Yoke mounted only.
- Yoke mounted when possible - depends on power supply of a/c and windshield configuration.
- Yoke so you do not have to search for the unit and then wait for it to acquire satellites.
- Yoke, convenience.
- Yoke, direct in line for pilot observation, less risk of damage.
- Yoke.
- Yoke.
- Yoke.
- Yoke.
- Yoke. Hands free flying.
- Yoke. Semi permanent less to be concerned about.
- Yoke only.
- Always use yoke as it simplifies operation.
- Always yoke mounted in case experience turbulence.
- Advantages of yoke mounted are easy to view, portable for other uses. Not expensive to fit to a/c, easy to remove, less chance of being stolen. Panel mounted is the same as other nav aids and radios for IFR and professional flying panel mount would be the only way for approval to be granted i.e. by CAA.
- Secured is better.
- Prefer yoke mount.
- My Garmin 55 has a mount and through that I can use aircraft power. It will take 6 volts to 48 volts.
- The GPS 55 is both. I use it yoke mounted for convenience sake. It is one less thing floating around the cockpit that way. I can just read info off it without having to look for it, pick it up etc.
- The yoke mount as it is right in front and is easy to read.
- Fixed - one hand use easier.
- Mounted only in use.
- Mounted. Easier to concentrate on the flying.
- If I had a yoke mount I would prefer this position!

Panel

- Always mounted on panel when in aircraft. Should never be used handheld when flying.
- Generally panel mounted as long as it is easy to view as I find yoke mounted GPS to make my controls feel cluttered.
- GPS is mounted on panel- to hard to read on yoke.

- Handheld - mounted on panel.
- I mount mine on top of the instrument panel not the yoke.
- In f/w my GPS is velcroed on instrument panel. In helicopter GPS is on my kneepad.
- Mine is a yoke mounted model. Which I don't like in the C185. I mount it in middle of dash so I don't have to look down at it.
- Mine is panel mounted.
- Mounted in instrument panel.
- Our GPS is mounted on the dashboard - it is a handheld GPS though.
- Prefer panel mount.
- Used console only.

Handheld
- Handheld because the yoke fitting is so hopeless.
- Handheld due stick.
- Handheld. More comfortable to operate while handflying.
- I fly mostly super cubs, beavers and a CT4. None of these have a suitable yoke.
- Do not use yoke mounted. These are dangerous obscure gyro horizon and DI/HSI and interfere with basic instrument scans.
- Don't like yoke mounted GPS's - get in the way.

Neither
- Neither, they are both dangerous.
- Neither. Dangerous!

Where would you prefer the GPS to be positioned and why?

Top of Console
- Bottom of window so you can see it easily.
- Displayed on console.
- Either on top of the instrument combing or at the top of the radio stack. Usually I place mine under the compass on top of the panel. Yes the compass does move 5° or so, but who needs a compass now?
- GPS is mounted on top of the instrument console angled to left hand seat - no reason to change.
- I mount mine on top of the instrument panel not the yoke - i.e. never hand use - tried that once and dropped it!.
- Top of dash.
- Top of dash. Just above instruments under dash sunvisor.
- Side of console or top of console (helicopter).
- On top of console to avoid periods of look-down in a VFR situation.
- On the dash - see it better.
- On top of dash, viewing ease.
- On top of the dash - keeps your eyes outside as much as poss.
- On control column - easily visible don't need to look down for long periods of time.
- Mostly residing at the top of the instrument dashboard. In turbulent conditions the GPS attached firmly to the dashboard. I find Velcro is a suitable material.

Panel
- A permanent fixture in panel to avoid theft.
- Above flight director or AH.
- Adjacent flying instrument 'T' include in scan (providing good screen).
- At eye level for easy scan reference.
- At or near top of instrument panel, to minimise 'looking inside'.
- Beside flight instruments.
- Built into comms stack on instrument panel.
- Centered just below eye level because other pilot can also use it.

- Central quadrant.
- Central to pilot, easy to read, no parallax.
- Central, high up, so as not to distract external view.
- Centrally at easy arms length. So unit can be seen and programmed easily.
- Centre of cockpit.
- Centre of instrument panel and slightly left. I found if I was using it for a letdown (Africa) it was helpful to have more in front of me then to the side. There was a tendency if it was positioned a long way off to one side to make you feel a little disoriented (letdown only).
- Centre radio stack - readability.
- Console, easy to check, only position since it is a portable unit.
- Control box among the radio panel with a display alongside HSI/RMI.
- Dash mounted looks better, less chance of theft.
- Dash mounted so it is included in the scan.
- Directly in front of me. As it is part of my instrument scan.
- Directly in front of pilot to allow ease of monitoring.
- Directly in front of pilot to be able to see the LCD in all lights.
- Directly in front of you because the screen is hard to read from an angle.
- Directly in front- convenience.
- Either position i.e. panel or yoke would be ok. Perhaps a slight preference for panel mounted.
- Fixed on panel if space was available.
- For our operations just below your eyeline so its easy to go in and out of the cockpit with your scan.
- GPS face at right angles to pilot vision. Position irrelevant.
- GPS is panel mounted with fixed aerial and select switch for CDI onto No 2 nav head.
- High on panel.
- High on panel.
- High on the instrument panel to the right of straight ahead.
- High up (shoulder height) and to one side (right) because of accessibility to display and keypad.
- In a fairly 'front on' position, anywhere off centre from line of sight and it becomes hard to read.
- In a two pilot crew situation - accessible to both pilots - single pilot on the C/W.
- In centre of dash away from primary instruments so I am not distracted by it when navigating on instruments.
- In front of pilot for ease of reading and adjustment.
- In front of you in the panel.
- In instrument panel, easy to operate and view.
- In panel - security and with other nav aids.
- In panel near top of stack for easy viewing.
- In pilot line of vision at eye level (or as near as possible) and be swiveled for use with other crew members.
- In place of redundant navaids such as RNAV, in normal comm./ nav panel or stack and on installations reflect: pure ergonomics, commercial pressure to fit in a hurry without regard to downstream effects.
- In the comms stack - easily accessible, logical place.
- In the instrument panel in full view of the pilot. Our GPS is mounted in the centre console between the pilots which means it's completely out of the pilots scan.
- In the middle of console. Readable for two pilots.
- In the nav comm. stack/ suits scan/ only place it would fit. At present mounted on coaming.
- In the panel as the yoke mount does obscure other instruments.
- In the panel but no room in stack.
- In the panel up high. Yoke is too close to use, takes time for the eyes to adjust.
- In the panel.
- In the radio stack - access and comparison with nav and DME data.
- Incorporated in instrument panel clustered with nav aids.
- Instrument panel mounted. It is out of the way and only requires attention when needed.
- Instrument panel near DG.
- Instrument panel.

- Instrument panel. As for VFR operations or reference should be outside but if mounted on panel it can be incorporated in scan.
- Integral part of instrument panel.
- It's real good where it is!. In the dash.
- Line of sight - safety.
- Mid panel available to both pilots, but clearly visible and useable single pilot interfaced.
- Middle of instrument panel for easy viewing.
- Mounted in the panel.
- My GPS is positioned with its top level with the top of the instrument panel hard back against it directly above the yoke. Eyes move about 25 off the horizon to read it and. refocusing is not required between the GPS and any other instrument.
- Nav stack.
- Nav station works well for military operations.
- Near top of panel - on yoke always looking down into cockpit too much.
- Nearer the centre of the panel.
- No change with type.
- Obviously the unit is best panel mounted. I simply put mine on top of the instrument panel where it is secured.
- On a bracket mounted to the left of the instrument panel so it does not turn with the controls.
- On dash as it is more in line of sight i.e. don't have to look away from windscreen and dash, doesn't move like yoke.
- On dashpanel above main instrument panel i.e. on coaming.
- On main avionics rack near the top. Perhaps just below Audio panel. Due to regularity of use, must be accessible.
- On panel.
- On the instrument panel. Feels a little cumbersome on the yoke at first.
- Panel - because its more out of the way (from controls) and part of instrument scan.
- Panel - ease of reading and cockpit tidiness.
- Panel - reduces clutter in a small cockpit.
- Panel - with other nav instruments.
- Panel mount - integrated nav aid.
- Panel mounted - for readability and entry of data - ours are mounted on centre of glareshield and angled for pilot view.
- Panel mounted - less obtrusive.
- Panel mounted for scan.
- Panel mounted in direct view if possible.
- Panel mounted.
- Panel mounted.
- Panel or yoke.
- Panel, ease of use, less clutter in cockpit with pax on board.
- Panel, plus emergency handheld or battery option on panel mounted.
- Panel.
- Part of nav display - why- primary nav instrument, way ahead of beacons.
- Permanently in the instrument panel.
- Presently at bottom of radio stack in Grumman dashboard, would prefer more in line of sight for better legibility.
- Presently fitted in lower console abeam left hand, find it too far back.
- Probably on top of panel with glare shield for easy removal for simulator training or programming if required.
- Rack mounted near other radios. transponder etc. Ease of sight, use and tidiness.
- Radio console.
- Repeater up front for the pilots.
- Right in front of eyes if poss. Why, used a lot and easy to see.
- Right panel but angled towards left seat i.e. in front of instructor but able to be seen by student. For XC use by pilot or student just right of instruments.
- To avoid theft only considered fixed installation in avionics rack as installation is in rental aircraft.

- Top centre instrument console, glance at it without looking totally away from outside a/c.
- Top instrument panel.
- Top of instrument panel - as only have to look down slightly to view.
- Top of instrument panel above AH so to limit eye travel so being able to keep eyes outside as much as possible. VFR and help scan IFR.
- Top of panel or in panel.
- Where we have it on panel very easy to read there.
- Yes becomes integral part of avionics not an 'add on'.
- Dash mounted. Again for convenience. Yoke mounted is ok but the cords (power, aerial etc.) everywhere can become a problem.
- May position it on the panel rather than on the yoke, to facilitate power and aerial connections without needing flexible leads.
- Either position i.e. panel or yoke would be ok. Perhaps a slight preference for panel mounted.

Yoke
- Yoke (but have never actually had one positioned there).
- Yoke - ease of reading especially at 58 years of age!
- Yoke - its a compact unit and in this position is comfortably within the normal instrument scan.
- Yoke - within close reach and sight and not hiding other instruments (perhaps with a panel mounted GPS, after use I may prefer this, but depends on position in mount as hands need steadying in bumpy conditions!).
- Yoke ease of use and most info in clear line of sight.
- Yoke mount as it is right in front and is easy to read.
- Yoke mounted - multiuse, position good.
- Yoke mounted hand held for easy accessibility.
- Yoke mounted is fine.
- Yoke mounted on control wheel is in pilots centre vision for single pilot operation.
- Yoke mounted, easily accessible and easy to see and steer by.
- Yoke mounted.
- Yoke.
- Yoke.
- Yoke.
- Control column mount. Nice eye position. No parallax error.
- Control column, access and observation.
- Control yoke.
- At the moment it is on control column. I had it mounted on dashboard but in certain lights could not read it.
- Happy with yoke mount except for external wires etc. from GPS.
- Have flown with Trimble dash mounted unit but the yoke mounted Flightmate is definitely easier.
- On the yoke for ease of use of reading and adjustment.
- On the yoke for good visibility.
- On yoke because it is easiest position to read.
- I prefer it where it is (yoke).
- On yoke. Easy to read and adjust.
- Yoke or panel.
- Maybe yoke, haven't tried.

Other
- It is in a good position as it allows the jumpers to view the GPS before they jump out.
- Handy.
- No preference.

Appendix H: Data and Statistical analysis files

Data and analyses used in this study are available in the following sub-appendix files[1] H1 to H14 located on a floppy disk at the end of this thesis. The files can be viewed through Word for Windows 6, and SPSS for Windows 6 programs.

Sub appendices	File name
Appendix H1: GPS survey raw data	(H1.sav)
Appendix H2: Sample demographics Chi square analysis	(H2.doc)
Appendix H3: One-way ANOVAs on general design rating items	(H3.lst)
Appendix H4: One-way ANOVAs on control rating items	(H4.lst)
Appendix H5: One-way ANOVAs on display rating items by display sub-groups	(H5.lst)
Appendix H6: One-way ANOVAs on display rating items	(H6.lst)
Appendix H7: Factor Analysis on design general, control and display items	(H7.lst)
Factor plot in rotated factor space for general items	(H7a.cht)
Factor plot in rotated factor space for control items	(H7b.cht)
Factor plot in rotated factor space for display items	(H7c.cht)
Appendix H8: One-way ANOVAs on accessories design factor	(H8.lst)
Appendix H9: T-tests on paired confidence items	(H9.lst)
Appendix H10: One-way ANOVAs on confidence items	(H10.lst)
Appendix H11: Factor Analysis on attitude items	(H11.lst)
Factor plot in rotated factor space for attitude items	(H11.cht)
Appendix H12: One-way ANOVAs on attitude factors	(H12.lst)
Appendix H13: Factor Analysis on behaviour items	(H13.lst)
Factor plot in rotated factor space for behaviour items	(H13.cht)
Appendix H14: One-way ANOVAs on behaviour factors	(H14.lst)

[1] Word for Windows 6 files end in .doc (text)
SPSS for Windows 6 files end in .sav (data), . lst (output), and .cht (chart).

Appendix I: User Comments On Checks And Errors Using GPS

What error checks do you perform?

Checks (135)

- 2nd person verification, 1st person double check.
- ADF, map reading, basic nav plot.
- After loading the NZ if waypoint database - double checked all co-ordinates - then check when used.
- Against ADF, VOR, DME.
- All navigation information is on screen - so a visual check - also check against VOR.
- Always note track and distance from map and use DR nav to confirm GPS information. Once validated use GPS but maintain DR trackplot.
- By cross reference with known practice - comparison with HSI and magnetic compass and DME - comparing lat. and long with master GPS file of co-ordinates.
- Check 'on track' - check that data fits mental model - direction distance, estimated time.
- Check A-B function with chart.
- Check against VOR, ADF etc.
- Check airport lat./long with VFG every time. Never assume its correct. Other people use the aircraft.
- Check altitude, check known positions.
- Check as above and compare with VOR/NDB information etc. in flight.
- Check course and heading off IFR chart or route notebook made personally from measurements off charts.
- Check distance and track on charts and cross check with GPS.
- Check for reasonableness from maps etc. Check that planned track and distance are reasonable (Visual flight).
- Check lat. and long of coordinates during preflight/ run up of route to be flown (checked by chart).
- Check lat. and long with cross ref. to map, follow flight on map.
- Check lat./long of flight planned points and cross check distance and tracks.
- Check location of waypoints visually.
- Check number of satellites. Check nav information against other sources.
- Check on VOR radials (where VOR is fitted) Check on DME - Visual position checks.
- Check position on map with distance and bearing info to confirm position.
- Check position of GPS navaid against charts.
- Check sat quality, present position with ONS, distance to go with DME, G/S etc.
- Common sense i.e. is the airport in this direction and about that far away.
- Compare course/distance with manual planning on map prior to flight.
- Compare information displayed with other aircraft instruments and prior flight planning.
- Constant verifying between GPS and charts.
- Correct information is in the user database, check track against A/c compass. Check ground speed against DME, check bearings against VOR.
- Cross check against map and general dead reckoning.
- Cross check GPS to map occasionally but usually rely on GPS as being accurate.
- Cross check position from conventional navaids - position of stored data; integrity from RAIM warning, position estimated accuracy.
- Cross check position on chart with distance to go.
- Cross check VOR/DME - GPS.
- Cross check with DME and VOR radials. If using 'goto' always check lat./long position corresponds to map.
- Cross check with map/VFR.
- Cross check with normal IFR instruments VOR/DME ADF.
- Cross check with normal nav methods.
- Cross check with VOR/NDB/DME information for IFR operations and parachuting visual check.
- Cross checking - VOR/DME.
- Cross checks with other RNAV's. All database inputs triple checked.
- Cross checks with published co-ordinates.
- Cross ref. with VOR/DME etc.
- Cross reference between aircraft and base station information.

- Cross reference with maps for co-ordinates VTC for airport lat. and longs VOR etc.
- Database satellite availability.
- Distance with DME, track with VOR and Terrain, track and drift with compass and terrain.
- Distances. So as to make sure all is well in flight planning.
- Double check coordinates with VFG.
- Double check data as entered on screen.
- Double check data number of times before using it operationally. I do this before going flying.
- Double check entered data.
- Double check entry positions and cross check route tracks against charts.
- Double check loaded data - also get another pilot to check it.
- Double check position reports input always double check pilot/co.
- Double check when entering waypoints etc. into unit.
- Double check with ADF, VOR and map datum's, map reading!
- Double or triple check lat./longs, check bearings/ distances against relevant map.
- DR with conventional nav.
- Enter w/point and recheck from chart lat. and long are correct. Use VOR and/or ADF to confirm direction, confirm with heading from IFR chart.
- Estimated position error, cross reference with map and correct lat./long for destination.
- F/planning - use correct lat. and long. Nav against VOR, DME, ADF - common sense.
- First load of jumpers per day verify 'spot' which they exited at as being correct. GPS is a guide only visual spot is primary ref. and always carried out clear of cloud!.
- GPS heading against chart.
- Ground features and ADF/DME.
- I check that the GPS has sufficient no. of satellites to operate. I cross check information with map and visually identify terrain I am flying over.
- I check the bearing and range against the chart when flight planning.
- I use aerodrome reference points and nav aid reference points published by Airways Corp.
- In hand at night without autopilot, no time for error correction, revert to map reading, bearing and time.
- Independent data entry check, where possible prove waypoints etc. in VFR conditions prior to use. Data alteration prohibited for perm routes, waypoints. temp WP positions allocated.
- Know position.
- Lat. and long - plus general knowledge of where it should be taking us and compared with conventional nav gear.
- Lat./long input.
- Lat./long position with chart information.
- Lat./long, VFG cross checks.
- Longitude and latitude.
- Look out the window and check VFR!.
- Look outside - just allows better tracking as at 10'000' the view of the DZ. is largely obscured.
- Maintaining course tracking by map reading and time keeping.
- Map backup, calculate groundspeed by time and distance.
- Map following and mental DR.
- Map read when I can, use VOR and DME when I can.
- Map reading to check track and E6B computer to check time to go; ground speed, ETA etc.
- Map reading.
- Map reading.
- Maps, charts, radio, ADF, VOR, compass references.
- Monitor battery condition and EPE.
- Monitor nav screen information with what I expect. Map reading.
- Monitor track against ADF and VOR indications.
- Monitor/ fly using primary aids. Always radar monitored if not on promulgated track.
- Mostly cross referenced with visual references/ charts.
- Nav plane as normal for VFR flying and see if the GPS is telling me the same. Check first in flight when using GPS if it is working normally.
- Nav. altitude.

- Navigation aid overhead position reporting to nav aid overhead indication by aircraft instrumentation.
- On ground after programming check track and distance showing is same as from charts.
- Only error on home strip, this being set drift or de-tune.
- Position at departure airfield as you would a VOR (radial distance).
- Pre-flight check, to make sure route makes sense with flight log.
- Quick measure with ruler to check distance, check map.
- Read input carefully before 'enter'.
- Recheck lat. and long after feed in.
- Refer charts, cross check VOR and ADF and DME all the time.
- Refer to DME, VOR, ADF and location.
- Run normal nav with maps and clock.
- Satellite strength and enroute re-check data selection using goto function button to verify station/ destination.
- Satellite strength, number. Verify against known trip distances and courses. I do a lot of repeat flights.
- Setting up - check lat. and long - bearing and distance and compare with chart/radio aid information.
- Sight map reading.
- That tracks would seem sensible from your current position.
- Time, datum and mode.
- Track error.
- Track, drift, map read to confirm position. Use 'goto' function to check waypoints along or close to track.
- Triple check all input co-ordinates.
- Visual and physical check against the flight log.
- Visual check.
- Visual e.g. ref. maps.
- Visual map reading, NDB checks, time and distance run.
- Visual nav check.
- Visual navigation.
- Visual ref.
- Visual reference points.
- Visual track checks.
- Visual waypoint checks.
- Visual.
- Visual.
- VOR- DME.
- VOR/DME verification of GPS position regularly.
- Watch carefully. Check GPS course against map heading.
- Watch for any error messages.
- When cross country VFR, you are always aware of your position. Experience/local knowledge means that I don't often check for errors, but you are always aware of the changes occurring- like checking location, groundspeed vs. airspeed etc.
- With DME etc.
- X-check ADF, DME, VOR.
- X-check against VOR, NDB, DME.
- X-checking DME and CDI information with existing nav equipment i.e. HSI, DME, RMI.

None = 15
NA = 7

What are your most common input errors?
Errors = 93

- Airport lat./longs.
- Base station lat. and longs to a high enough level of accuracy.
- Checking altitude information on user waypoints.
- Co-ordinates in back to front.
- Co-ordinates: format and digit errors.
- Double key in bumps.
- E-W, S-N co-ordinate input errors.
- Either transcription errors from map or transposition of numbers when entering data into GPS.
- Entering wrong long and lat.
- Exacting co-ordinates of airstrips from verbal descriptions of location.
- Finger trouble, hitting the wrong key.
- Finger trouble.
- Finger trouble.
- Finger trouble.
- Finger trouble.
- Finger trouble.
- Finger trouble. Wrong waypoint coordinates.
- Forgetting the sequence to obtain the correct information.
- Forgetting to change from the default - Northern hemisphere to South.
- Gave an incorrect ETA because I had put in an incorrect lat. for a reporting point - happened once.
- Getting direct to and finding us saving present position.
- Go to wrong position.
- I mistook a P for an R.
- I only use waypoints downloaded from PC and so far no errors have shown themselves! But no doubt there will be errors of entering faulty lat. and long in the database.
- Inadvertently pressing a button twice in turbulence resulting in a change of mode or number or letter.
- Incorrect alpha numbers.
- Incorrect lat. and long but if you are navigating correctly your map and tracks will show up, also the ADF and VOR will show up your mistakes.
- Incorrect lat. and long.
- Incorrect lat./long input or incorrect naming of autostore waypoints.
- Incorrect map datum once when becoming familiar.
- Incorrect mode selected i.e. 'DCT TO' or 'FLTPLAN'. Also incorrect ' source' selected to autopilot i.e. VOR/ONS/GPS.
- Incorrect mode.
- Incorrect numeral/alphabet 2° multifunction keys - i.e. may scroll wrong way.
- Incorrect waypoint information.
- Incorrectly putting in minutes and seconds re decimal or 1/60's.
- Input errors.
- Input wrong number in lat./long.
- Inputting aerodrome location instead of say VOR location or NDB which can vary e.g. Wairoa, Kaikoura.
- Inputting incorrect lat./long information.
- Keyboard errors.
- Keying in the waypoint name incorrectly.
- Keying in waypoints by cursor movement to wrong alpha, have been lucky to detect error before use.
- Lack of pre-flight planning.
- Lat. and long and as in 85 once not many problems at all with a little care and pre flight planning there is virtually no errors.
- Lat. and long errors.
- Lat. and long format errors.
- Lat. and long input if not double check selection of wrong waypoint with similar name or symbol.
- Lat. and long, waypoint reference number or name.
- Lat. and long. Particular caution needed during flight in turbulence.

- Lat. long errors in database.
- Lat. or long figures
- Lat./long co-ordinates transposed.
- Lat./long input.
- Lat./long transposition chart to GPS - easy to check by comparing with manual planning on map prior to flight.
- Latitude and long position of destination.
- Misread waypoint.
- Misreading RNC chart (happened once).
- Mode selection.
- Navigating off the wrong GPS waypoint/navaid, bringing up the wrong next waypoint due to poor description of waypoint on display.
- Northern hemisphere position.
- Not being exact with information put in to find small strips.
- Not properly converting sexagesimal (off chart) to decimal (for GPS input) although most of the new charts are now decimal. Listings in AIP/CASO are still sexagesimal however. Errors normally picked up during a double check or recheck.
- On Garmin each button has 3 options with L or R to select letter. Sometimes press arrow wrong direction but soon note wrong spelling and so correct - no problem!
- Only having the wrong user fix set 'goto'
- Over/under estimating wind strength, direction at altitude.
- Pressing wrong mode button.
- Pushing incorrect button.
- Pushing wrong button.
- Put in the wrong IDs.
- Putting in incorrect lat. and long.
- Putting in wrong letters/symbols when entering data therefore a database is a very good idea i.e. AVD.
- Route working in reverse i.e. forget to push inverse.
- Sometimes a bit difficult to select 'next' while flying. Preplanning and entering desired waypoints in logical sequence helps e.g. A B C etc.
- Spelling errors in inserted waypoint names!
- Those promoted by unfamiliarity with seldom used functions. User friendliness.
- Transposing numbers - particularly lat./long.
- Turning the wrong way to intercept track.
- Use database so very little inputting.
- Very few. If any finger trouble pushing input buttons - but not the fault of the equipment.
- Waypoint co-ordinates.
- When entering airfields which are not in data base. Have to enter latitude/ longitude, which I recheck twice after entering. Also don't let the database eye!
- When trying to input a waypoint.
- WPT put in wrongly preflight.
- Wrong buttons pushed necessitating re-inputting data.
- Wrong country for the same ICAO designator.
- Wrong fix (airport).
- Wrong lat. and long (not airports).
- Wrong lat. and long.
- Wrong lat. and long.
- Wrong Latitude or longitude.
- Wrong letter groups, on letter; often last letter, one letter out.
- Wrong selection of IDENT - immediately obvious on check.

Nil =49

What are your most common misreading errors?
Errors = 37

- 10 as 18 and vice versa.
- Altitude.
- Wrong CDI bar source (GPS/ONS/VOR).
- Bearing for distance occasionally.
- Becoming oblivious to its persistent warnings (red light on instrument, repeater on panel) particularly when it goes onto dead reckoning. If this occurs say on approach or takeoff it retains the wrong info (G/S, track) etc. and until it resumes GPS I have navigated into the cruise with the wrong info.
- Caused by poor readability of display in sunlight.
- CDI bar.
- CDI errors, do not understand function fully.
- Confusing 'track to' to track made good.
- Confusing AA airport with AA VOR with AA NDB.
- Correct lat. and long entered.
- Displacing digits.
- Drift correction.
- Due to light change due different headings sometimes difficult to read figures due reflection on screen and size of figures.
- ETA's
- Forget to switch RMI from GPS to VOR.
- GPS display 000 not 360. This is a very non proactive thing to do. I've never heard of runway 00?
- I sometimes misread the line because the screen is small and too close to me.
- I took a while to get familiar with correct inputs, but now have 100% confidence in GPS 55.
- Initially 'D-bar' s steering but this only for 1st couple of flights.
- Lat. and long in as much as north and south getting swapped as does east and west.
- Lat. and long.
- Misread where the track is relative to aircraft position and heading.
- Misreading the titles i.e. the small abbreviations e.g. RNG, ETE, DTK. Usually just because I only glanced at it without reading it properly.
- Not seeing that the fix is the wrong one until you decide something is wrong.
- Pilots fingers.
- Poor backlighting making the display difficult to read.
- Putting in wrong 'minutes'.
- Set up putting wrong co-ordinates.
- Swapping between course to steer, course made good, track and not noticing which one I've selected.
- Time, it can be std in UTC, or just ETA depending on how screen default on goto function.
- Track and Hdg.
- Track error left or right readings
- Waypoint abbreviations.
- Wrong co-ordinates.

None = 90

- Can't think of any currently, not current on use.
- Can't think of any.
- Have not had any yet.
- Have not misread information to my knowledge.
- Haven't had any.
- I am not aware of any misreading.
- I have not had any misreading errors yet.
- Negligible.
- Never been a problem.
- Never had any on the Garmin.
- Nil specifically.

- Nil to date.
- Nil, always x-check with VOR, DME, NDB.
- Nil x 15
- Nil. Inputting original data from map/ into database.
- No common errors.
- No experience of this.
- No problems to date.
- None - if you know your instrument.
- None x 27
- Not sure.
- Nothing specific.
- Once again, I don't recall any.
- Display very clear, never had problems.
- Not aware of any as yet.
- N/A. x 27

Appendix J: User Comments On GPS Training Requirements

What training did you have on the GPS? (51)

Course (6)
- Company training in Air Chathams.
- Manufacturers course.
- Training course Papanui flying school.
- User manual, course taken by local rep.
- User manual, distributor provided formal training course.
- User manual, in house ground course.

Demo/briefing (22)
- I was told briefly about how to access the airport database and what buttons to push but essentially I am self taught on this model.
- Introduction by another pilot, then (still) reading manual.
- Line operations with experienced crew.
- User manual, two pilot experience, explanations were verbal.
- User manual, 30 minutes with flying instructor on ground.
- User manual, a little instruction.
- User manual, and shown by an instructor.
- User manual, briefing and demo by experienced user of model I operate.
- User manual, briefings from commercial pilot.
- User manual, assistance inputting data from trained navigator.
- User manual, demo from owner.
- User manual, demonstration by another pilot, trial and error.
- User manual, friends help.
- User manual, oral briefing.
- User manual, review with CFI.
- User manual, other flyers demonstrating it.
- User manual, other pilots.
- User manual, supplier help.
- User manual, some instruction from the retailer.
- User manual, word of mouth by owner, photocopied and read the manual.
- User manual, other user training.
- User manual, sales person.

User manual/practice (18)
- User manual, experience i.e. on the job training.
- User manual, experience is best tutor and have taught ground course on GPS - 3 1/2 years use.
- User manual, a lot of playing.
- User manual, and plenty of hands on use in the AIR.
- User manual, and practice on known routes.
- User manual, and pushed buttons.
- User manual, taught myself from book.
- User manual, company written manual.
- User manual, decided to buy one after a couple of IF flights in an aircraft with GPS, picked up the basics on those flights.
- User manual, home practice before use.
- User manual, learnt myself.
- User manual, lots of hands on use.
- User manual, practice.
- User manual, self teach trial and error.
- User manual, use of carry case for lecturing in 'takeout' mode.
- User manual, used in cars and when tramping and climbing.
- User manual, using it.

- User manual, very little instruction - personal study only.(unfortunately) long learning process.

Other (3)
- I am a GPS expert from the survey industry.
- User manual, It has a simulator mode (You use a lot of batteries).
- User manual, video.

None (2)
- None
- Self taught.

What training do you think is needed on the GPS? (n=118)
Course /theory (42)
- 1/2 day course on its limitations for navigation.
- A specific ground course would have been good.
- For IFR use 1/2 day classroom covering use and precautions.
- Formal, specific to model used.
- GPS workshops, supplier support.
- Ground course- maybe 2 days.
- Human factors, equipment use and limitations.
- Its desirable to having instruction on any new system, GPS included.
- Local flight training workshops.
- Some inexpensive short course.
- The limitations of the information being given.
- Training course from school.
- Trimble have a video which I think would be great. User manuals are ok but some professional training would be best.
- User manual, a short course would certainly speed up ones ability to become a proficient user of GPS.
- User manual, also ground courses.
- User manual, and courses.
- User manual, course by training establishments may be helpful to some.
- User manual, course highlighting common gotchas'.
- User manual, courses held as many people have trouble with electronic gizmos with buttons.
- User manual, courses taken by qualified tutors.
- User manual, courses would be great.
- User manual, courses.
- User manual, flying school training would be very beneficial.
- User manual, ground course instruction.
- User manual, ground course so pilots know how to use more than the 'goto' function.
- User manual, demonstration (air and ground), Instruction on human factor errors associated with GPS.
- User manual, no deficiencies are mentioned - these should be highlighted.
- User manual, night class or similar.
- Manual very hard to follow takes a long time to learn to use GPS. Night class
- User manual, nav course using GPS units.
- User manual, in ground course if ever primary aid.
- User manual, limitations, GPS can get you into lots of problems if not programmed correctly.
- User manual, Maybe a 3 hour brief on how what why when type of thing. I would like to understand more about how it works.
- User manual, non instrument rated pilots could use training.
- User manual, perhaps some kind of lectures/seminars would be beneficial.
- User manual, Pilots wishing to use GPS really need to spend whatever time is necessary learning about the various functions etc. It can be very helpful for navigation but it can be quite distracting if your knowledge of it doesn't cover the task you require from it.
- User manual, would suggest first time users attend course.
- User manual, school.

- User manual, transferring GPS nav information onto charts for position checking.
- User manual, some discussion on possible failures, hazards.
- User manual, some less experienced folk may need tuition on GPS uses and cautions!.
- Basic functional training - training in when not to use - VFR in cloud - it does happen!.

Briefing/Demo, use under instruction (39)

- Ideally 'play with it' on a dual flight as navigator.
- Practical instruction.
- Practical training.
- Practical demonstration of each function would be helpful.
- To be covered by flight instructor, followed by small written exam.
- Normal company brief type lesson and hands on practice.
- User manual, and practice. Check ride with proficient user.
- User manual, briefing from user.
- User manual, ATC to tell us how they would like us to use them.
- User manual, briefing by experienced operator on particular model.
- User manual, briefings from experienced users who are instructors.
- User manual, briefings on pitfalls of direct/off airway flying.
- User manual, but it would help to have someone explain the functions when first acquainted with the GPS.
- Basic personal instruction.
- User manual, contact with other users.
- User manual, correct instruction by supplier on use - features and limitations - checks that can be made to verify correct operation of the unit e.g. noting position on actual a/d ref. point.
- User manual, dealer training, briefings.
- User manual, enough to be able to use it quickly and efficiently by this usually comes with experience.
- User manual, experienced user running through it with you.
- User manual, experienced person.
- User manual, discussion with other users.
- User manual, demonstration (air and ground), Instruction on human factor errors associated with GPS.
- User manual, practical application plus user experience assistance.
- User manual, practical instruction.
- User manual, practical instruction.
- User manual, for VFR some dual flying with experienced user would help especially in getting full use i.e. wind checks, best level to fly etc. Some users are not taking full advantage just using track to fly.
- User manual, if equipped, instructor/owner should show use of.
- User manual, instruction by competent operator.
- User manual, oral briefing.
- User manual, more operational training.
- User manual, operator based training for routes etc. and its specific functions, settings, modes to be utilised and how.
- User manual, instruction from qualified person.
- User manual, instructor would be a help.
- User manual, instruction does also help.
- User manual, in flight.
- User manual, training with instructor would help.
- User manual, someone that has practical experience , I believe, would help.
- User manual, some help from another user.
- User manual, pilot interaction.

Rating/exam (12)

- Specific GPS rating like VOR/DME endorsement etc.
- As for other nav aids.

- Same level as for VOR or ADF.
- To be covered by flight instructor, followed by small written exam.
- User manual, basic problems with GPS navigation etc. as part of the commercial nav syllabus.
- User manual, rating.
- User manual, formal training included in type conversion.
- User manual, ground course incorporated in IFR training.
- User manual, heaps, it should become part of nav syllabus now, course, instructor check outs.
- User manual, incorporate into ab-initio navigational flights.
- User manual, incorporated in instrument training and ratings
- None until they become approved for IFR flight. Then part of IR. theory, CPL exams

Simulator (2)
- User manual, simulator
- User manual, simulator practice.

User manual and practice (19)
- User manual,
- User manual, a lot of playing on the ground and air.
- User manual, actual use.
- User manual, and practice. Check ride with proficient user.
- User manual, and lots of experience operating the same type preferably your own waypoint and route catalogue.
- User manual, better manual.
- User manual, agency/ importer training.
- User manual, better written user manual.
- User manual, plus correct attitude to nav technology, plenty hands on is needed.
- User manual, practical use.
- User manual, practice.
- User manual, practice.
- User manual, for VFR and practice.
- User manual, hands on , actual flight plans and deviations.
- User manual, I don't make the most of my GPS because I haven't taken the time to become familiar with all its operations.
- User manual, I think my manual could be improved, scenario training.
- User manual, depends on the model.
- User manual, the more you use it the easier it gets.
- User manual, using it.

Video (3)
- Trimble have a video which I think would be great. User manuals are ok but some professional training would be best.
- User manual, audio/visual instruction.
- User manual, combined with video would be extremely useful. The video could concentrate on how GPS works.

None (1)
- None until they become approved for IFR flight. Then part of IR. theory, CPL exams

What training would you like to see available for GPS? n = 138

Course (68)
- Course 1/2 day classroom covering use and precautions.
- Course 1/2 day on its limitations for navigation.
- Course Aero club level night courses would help many to get more out of GPS.
- Course Aeroclubs organised courses. Eventually incorporated in training for instrument rating.
- Course Agency/Importer training.

- Course Agent seminars.
- Course All VFR pilots should be made aware that GPS is an aid only and they must not discard normal safety procedures.
- Course Approved course.
- Course Basic courses at flying schools.
- Course Basic explanation in licence theory.
- Course Bit about theory and services available.
- Course Businesses that sell GPS should be able to provide training on use.
- Course Classroom and practical.
- Course Club instructions, briefings at club.
- Course Comprehensive course. more than 1 day.
- Course Consolidation course.
- Course Demonstration (air and ground), instruction on human factor errors associated with GPS.
- Course Distributors/suppliers flying schools/aeroclubs could run brief seminars - competency check may be useful.
- Course Evening classes.
- Course Fairly comprehensive.
- Course Flight school: RNZAC FTO courses.
- Course Formal training included in type conversion.
- Course Formal, specific to model used.
- Course Full product training from the supplier/dealer as required.
- Course General GPS course and some instruction on the type to be used.
- Course GPS seminars or how it all works - errors associated with GPS.
- Course GPS workshops, supplier support.
- Course Ground course would have been good.
- Course Ground course.
- Course Ground course.
- Course Ground courses available and video demos.
- Course highlighting common gotcha's.
- Course I think it would be difficult to develop a standard training package considering the variation. Some theory of operation and inherent weaknesses would be useful.
- Course I think they are very simple but a 1 day session not only on how to use a particular GPS but the principle on which it works would be beneficial.
- Course I would like to know whether I am getting the most out of it.
- Course Instruction courses by the manufacturer or a training organisation.
- Course Instruction courses.
- Course Introductory courses.
- Course Its desirable to having instruction on any new system GPS included.
- Course Lectures/seminars or some kind of course maybe.
- Course Manufacturer based courses run through aeroclubs and training facilities.
- Course Manufacturing company courses.
- Course Maybe a 3 hour brief on how what why when type of thing. I would like to understand more about how it works.
- Course Must know its uses and limits (It's only an aid to navigation).
- Course Nav course using GPS units.
- Course Night class at aero clubs by manufacturers.
- Course Night class or instructors knowledge passed on.
- Course None. I know how to use one! - PPL courses should talk about theory and use.
- Course One night refresher/user class.
- Course Perhaps day seminars.
- Course Rating courses.
- Course Rating or formal training in usage.
- Course The limitations of the GPS signals i.e. S/A.
- Course Training courses flying school.
- Course Training for new clients (PPL's).
- Course Training seminars.

- Course Tuition from experienced teacher is much better than learn it yourself.
- Course Weekend courses on ??? or different types available.
- Course with local aeroclubs would be useful.
- Course.
- Courses held free for all users (paid by manufacturer).
- Courses on navigating by GPS would definitely assist in maximising the potential of this system.
- Courses run once a year could be helpful.
- Courses taken by qualified tutors.
- Courses.
- Courses.
- Education for pilots regarding the useless nature of GPS as a navigation tool if waypoints and backup (i.e. get out of here) are not loaded prior to flight. Emphasis on not becoming preoccupied with GPS on VFR tasks.
- Some one who knows what they are doing to give a short course.

Video (6)
- Video - video briefing.
- Video demo available for purchase.
- Video For advanced functions short video might be useful.
- Video giving over the basics of GPS (the how and why it works), also on use of GPS for more common functions.
- Video, books, articles.
- Video.

Nav syllabus/exam (12)
- Nav training Included as part of basic navigation training like other aids.
- Nav training Included in PPL and Commercial Nav.
- Nav training Included in PPL navigation papers or aeroclub instruction given.
- Nav training Incorporated in CAA examination material.
- Nav training Incorporated into navigation and instruments syllabus.
- Nav training Instructors should check pilots and include GPS training in flying training.
- Nav training It should become part of nav syllabus now. Course, instructor check outs.
- Nav training Part of training.
- Certified by exam of sorts.
- Addition to theory papers for I/R and ATPL (maybe CPL/PPL too). IRT training similar to VOR/ADF now.
- As for other nav aids.
- Basic problems with GPS navigation etc. as part of the commercial nav syllabus.

Manual (5)
- Better user manual.
- Expand user manual.
- Just the manual.
- Operator (user manual) and operational specific.
- User manual.

Demo/briefing (26)
- Briefing by experienced operator on particular model.
- Briefings on pitfalls of direct/off airway flying.
- I would like to see aero club instructors with knowledge of GPS.
- Instruction by frequent user to raise awareness of uses.
- Instruction does also help.
- Lecture on basics required; not all functions though.
- More discussion.
- Nav exercise with the person in the copilot set for the first two hours of using the GPS in an airplane.
- Normal company brief type lesson and hands on practice.

- Not necessarily specific training but a form of check out as to user knowledge and ability to using in flight and cross check positions.
- Practical instruction at aeroclubs.
- Practical instruction.
- Practical instruction.
- Practical instruction.
- Practical nav training.
- Practical use.
- Practical use/instruction.
- Qualification available from instructors experienced with GPS.
- Same level as for VOR or ADF.
- Some instruction.
- Some.
- Someone that has practical experience through clubs and schools.
- Supervision in the input of data and how to get the best out of unit.
- System integrity checks and GPS limitations.
- That owners and users fully understand the user manual. Transferring GPS nav information back onto charts for cross checking position.
- User experience assistance.

Practice (1)
- Hands on, actual flight planned and deviations.

Simulator (2)
- Simulator and inflight dual practice.
- Simulator.

Other (7)
- Basic.
- Cannot comment until Airways etc. define their procedures.
- Depends on type.
- Depends very much on overall nav experience.
- Don't know.
- NA
- NA.

None (11)
- Nil.
- None, simple to use.
- None, we do it in-house.
- None.
- Not much.
- Not required.
- Ones ability to become a proficient user of GPS.
- Should not be necessary - if so, too complex and not user friendly.
- The more you use it the easier it gets.
- Thorough knowledge of types you use.
- Unsure.

Appendix K: User Comments On Difficulties And Possible Hazards Using GPS

What do you find difficult about using the GPS?

Learning (9)

- Initially learning how to input data and utilise the many available functions.
- Lack of exposure.
- Lack of knowledge about the GPS thus limiting more effective use.
- Lack of time spent studying the manual and lack of general aviation knowledge.
- Learning to master it and using boxes of batteries at night practicing.
- The GPS is capable of providing a great deal of analytical data which I feel is not of much interest to the average pilot. I found that learning from the manual was very difficult. Once mastered operation is very simple.
- Took time to learn how to use it. Not used to computer technology - getting too old.
- Trying to understand the instructions, sometimes it is hard to follow and not clear also multifunction keys and sequence of keying can be hard to recall (I've not had much experience though).
- There is nothing difficult about the GPS. The initial learning curve is the hardest. The manuals are written in such a way that it makes it more difficult to learn.

Computer literacy -Age (4)

- If you are not young have not used computers they are very hard to learn how to use, it can take weeks.
- Some difficulty for older pilots
- Understanding the instruction manual. I have not been used to computer language and also find instructions refer back to previous pages for continuation of operation and I tend to lose the trend.
- Took time to learn how to use it. Not used to computer technology- getting too old.

Manual (7)

- Working out how to use it by reading the user manual.
- I found that learning from the manual was very difficult. Once mastered operation is very simple.
- Understanding the instruction manual. I have not been used to computer language and also find instructions refer back to previous pages for continuation of operation and I tend to lose the trend.
- With this particular model which has few buttons and a rotary switch - initially it was a problem learning how to set up each mode, as the manual was written in 'computerese' which I found hard to follow. But the main problem is merely one of being 'current'. However, it's not really a problem after a few minutes of familiarisation.
- Poor user manual
- The way the manual is laid out. I have been told there are easier GPS makes on the market to use.
- There is nothing difficult about the GPS. The initial learning curve is the hardest. The manuals are written in such a way that it makes it more difficult to learn.

Practice (18)

- None with practice.
- Nothing after fully reading the manual and practice.
- Nothing after becoming familiar with functions available and operational data.
- Nothing really, ability and confidence of use comes with experience.
- The GPS is not difficult to use. Initial settling time is approx. 10 - 15 hours before gaining confidence, Great practice and user knowledge comes from entering the NZ VFG by the operator.
- Remembering all its functions because of my sporadic use of one. Once proficient with the unit it is very user friendly. The only bug in the system is that the screen can be hard to read in direct sunlight.
- Using frequently enough to retain all of the features/functions proficiently. Use in mod turbulence difficult - as in most aircraft.
- Lack of exposure.

- Being able to afford to go flying so I can actually use it! With this particular model which has few buttons and a rotary switch - initially it was a problem learning how to set up each mode, as the manual was written in 'computerese' which I found hard to follow. But the main problem is merely one of being 'current'. However, it's not really a problem after a few minutes of familiarisation.
- Some hidden functions don't seem obvious at first. The best way is to use the GPS every day until you become familiar with its vast capabilities.
- Using frequently enough to retain all of the features/functions proficiently. Use in mod turbulence difficult - as in most aircraft.
- I have not used it enough to remember it all.
- Not using often enough, changing functions, being aware of menu level.
- I have found the GPS reasonably straightforward to use. However, it does take a little time and effort to learn to operate its functions.
- Only the fact we can't use it more.
- This particular GPS I didn't have a great deal of time on - maybe 50 hours total flight most oceanic.
- Not having one in present aircraft.
- User friendly 'shortcuts' for recording waypoints, trip info and performance data and trip analysis - a case of needing to use the Trimble often.

Design (3)

- The ergonomics of the Transpak II are very poor. The functions are basic and easy to follow but the machine was designed to work in battle tanks and isn't suited to the cockpit of light a/c. I will change to a yoke mounted multi-function unit ASAP.
- The GPS generally doesn't update fast enough - this can cause inaccuracies when flying close to the fix. Dead reckoning needs to be employed between updates.
- There will always be a trade off between more buttons = more user friendly, and less buttons = more compact.

Controls (10)

- Required to push far too many buttons for information.
- Button size with flying gloves on; rotary switch would be better.
- Entering new waypoints in turbulence or while single -pilot IFR in cloud.
- Keypad too small.
- Prefer keypad.
- Manipulation of controls in flight as it is not mounted into the panel.
- Pushing the buttons, especially in turbulence, for next goto waypoint.
- Slow response to pressing buttons, it's like they have a time delay built in.
- The multitude of additional nav information available, and the small size of the buttons.
- Use of a keypad for data entry would be helpful, it is quite time consuming with inner and outer knobs.

Display (12)

- Display difficult to read at night.
- Hard to read in sunlight.
- Reading the display in bright light conditions.
- The only bug in the system is that the screen can be hard to read in direct sunlight
- Poor readability of display - you cannot read it with ease at all when heading into sunlight and must have the display at the correct angle to you. Not much use in 2 pilot operation.
- Seeing the display unless it is at a good angle it is hard to read.
- Size and brightness of display, impossible in some lights.
- Reading the display in certain light conditions.
- Very poor to read in flight conditions.
- Screen too small. Information to close together. Takes practice to isolate quickly the info you need at the time i.e. ETE, ETA.
- Poor display of function availability, it should be menu driven.
- The Garmin 55 does not display CDI and LEG or waypoint simultaneously also XTE and distance to go.

Functions / Complexity (42)

- There is a large amount of information in a small unit and yet the system of retrieving this information can be difficult.
- "RTE' function
- Advanced functions as we never use them.
- All the function buttons.
- Clearing user waypoints especially 9 nearest.
- Clutter of info and how to get it.
- Not using often enough, changing functions, being aware of menu level.
- Functions other than goto.
- Haven't mastered routes in sequence and getting rid of them.
- Lack of access to Sat data and receiver strength (sat integrity) during normal operations. Newer GPS's obviously overcome this problem, with "BITE".
- Navigation using route catalogue and inserting a waypoint during flight. It is easier to have all the waypoints entered and use the "go-to " function.
- Trying to understand the instructions, sometimes it is hard to follow and not clear also multifunction keys and sequence of keying can be hard to recall (I've not had much experience though).
- Only one function, that is renaming a waypoint.
- Waypoint management.
- Remembering the user defined waypoints, only able to see elapsed time to next waypoint rather than to destination.
- Poor display of function availability, it should be menu driven.
- Programming for flights.
- Programming for functions.
- Remembering all its functions because of my sporadic use of one. Once proficient with the unit it is very user friendly.
- It does not always do what you expect when you push a button.
- Its complexity, there are just so many things it can do its hard to absorb them all.
- Remembering how to do functions that you don't often use i.e. calculating wind.
- Remembering quickly how to get to the required screen/mode.
- Remembering the sequence to the scroll through all the many different functions req. when using some of the less frequently used functions e.g. trip plans/ winds aloft/ fuel plans etc.
- Remembering what all the function keys do and accessing all the potential information.
- Remembering where all the information on it is.
- Requires manual entry of OAT and CAS (TAS) and Hdg information to obtain actual enroute wind velocities
- Route planning
- Time spent in programming.
- Too many buttons to push in high workload situations. They (i.e. current models) aren't that user friendly although they will have to be for TSO approval to do instrument approaches.
- So many functions.
- Some hidden functions don't seem obvious at first. The best way is to use the GPS every day until you become familiar with its vast capabilities.
- Some of the functions which are not often used.
- The amount of functions in it, you can start to play around with it in flight and spend too much time looking down, not up and around.
- Nothing particularly but some of the functions are obscure and their value very limited.
- Using all the functions available. I really don't know all that it is capable of. (Just like my computer). I use the functions I need to navigate accurately, but that is all basically.
- Using frequently enough to retain all of the features/functions proficiently. Use in mod turbulence difficult - as in most aircraft.
- The Apollo 920 is very user friendly and once familiar with the basic functions is very simple to use.
- The multi functions i.e. one key is used for different functions and cutting the garbage information that's available out so as to find the necessary information.
- The multitude of additional nav information available, and the small size of the buttons.

- The need to 'deactivate' a waypoint in order to amend it. A lot of button pushing is required, especially single-pilot in a helicopter at night.
- User friendly 'shortcuts' for recording waypoints, trip info and performance data and trip analysis - a case of needing to use the Trimble often.

Database (3)
- Accessing fault in database.
- Finding a particular airport - whose runway is under 2000 ft - not listed and sometimes in the Jeppesen database even 2000 ft runways are missing.
- Database does not include minor airports in NZ so you have to enter them manually.

Position (4)
- Located in centre of panel in 2 pilot a/c, not in scan for IFR.
- Mainly all the cords etc. everywhere (cords for headset, intercom & GPS, things get in a tangle). Apart from that it isn't hard to use.
- Manipulation of controls in flight as it is not mounted into the panel.
- With yoke mounting it is difficult for anyone other than pilot to adjust the GPS controls.

Power supply (4)
- Tendency of power supply cable to slip from power pack.
- Must have good power supply.
- On the Garmin 2000 knowing how much power was remaining in the batteries and whether battery or external power was being used. If external power fails it automatically switches to battery power with no warning, what happens when the battery runs out!
- Power supply - no rechargeable batteries and quick drain of batteries.

Flight behaviour changes (8)
- In differential mode the aircraft has to be flown very accurately which can be very tiring with the low altitudes involved.
- It is far too accurate.
- Knowing and seeing - seeing you're way off track using conventional navaids but not being able to do anything about it.
- Maintaining accurate track at the same time as an adequate lookout.
- That the GPS takes a lot of attention and can divert you from keeping a good lookout.
- The amount of functions in it, you can start to play around with it in flight and spend too much time looking down, not up and around.
- The pilots possible slip in using GPS as a backup on a VFR flight which has caused some to get into positions of danger and caused fatalities.
- Forcing yourself to use double check and cross check procedures.

Standardisation (4)
- It is important to understand the operation of your particular GPS.
- With my own, nothing. Changing make/model takes a few moments to figure out what does what.
- Virtually nothing if using one set with proven data. It becomes second nature. Problems occur when using different brands and having to program data at short notice or having to temporarily mount sets leading to vibration and visibility problems.
- User friendliness, Transpak- all info is available at switch positions. Others- requirement to screen through various menus - less familiar = less likely to achieve satisfactory result.

No difficulties (52)
- Fairly easy once you master the basics.
- Nothing when you know how it works
- None with practice.
- Nothing after fully reading the manual and practice.
- Nothing after becoming familiar with functions available and operational data.
- For cross country VFR none.

- Nothing. I am biased toward the Garmin 100. The functions are handy and once proficient with the unit it is very user friendly. The only bug in the system is that the screen can be hard to read in direct sunlight.
- Nothing particularly but some of the functions are obscure and their value very limited.
- Nothing really, except perhaps waiting to get coverage.
- Nothing that comes to mind. I have found most to be user friendly, some more than others, but in general a very simple nav aid. It is important to understand the operation of your particular GPS.
- Nothing really, ability and confidence of use comes with experience.
- This model is very easy to use. (That is one of its main advantages).
- Nothing. The Magellan is user friendly.
- The GPS is not difficult to use. Initial settling time is approx. 10 - 15 hours before gaining confidence, Great practice and user knowledge comes from entering the NZ VFG by the operator.
- It is not difficult to use.
- It is not difficult.
- No difficulty with functions I use.
- Haven't had any difficulties using GPS to date.
- No problems encountered so far.
- No real difficulties
- No specific difficulties
- Nothing, common sense.
- Nothing much
- No problems x 2.
- Nothing x 17
- Nil x 5
- None x 2.
- N/A x 3

What problems have you had using the GPS? and b) How could these problems be avoided?

Practice/Learning/Knowledge/Manual (25)

- Suspected altitude accuracy, but found my expectations were a little beyond the GPS capabilities.
  b) Better understanding of GPS principles of operation and limitations.
- Systems.
  b) Refer to manual.
- As stated frequency or infrequency to get familiar. As with all sorts of other aviation add-ons. The philosophy is "Buy, fit and fly"
  b) Hands on induction.
- Understanding the instructions.
  b) Better worded manual.
- At the early stages - finger trouble
  b) Familiarisation and continuous use at the early stages.
- Firstly, just getting to know your way around its functions and knowing how to retrieve information from the database.
  b) Video on how to use your GPS or tuition would be most helpful.
- Time taken to input a waypoint in flight when not completely familiar with operations.
  b) Better training or knowledge before use.
- Getting enough simulation practice time to gain confidence.
- Getting familiar with the functions.
  b) More information in user manual.
- Lack of knowledge.
  b) More training.
- Hard to learn.
  b) Easier manual
- Initial operation.
  b) Practical inst.

- Only limited use.
  b) More exposure.
- Not enough use regularly causes stupid mistakes.
  b) Fly more often.
- Took time to learn to use it.
  b) Help from someone who has used one before.
- Just getting used to it. You set up a flight plan or route plan and then push the wrong button. Back to square one.
  b) Practice.
- Keeping current with little used functions.
  b) Better presentation of functions and switching from one to another.
- Initial use.
  b) Training.
- Mostly initially in learning to use it. If GPS become available as a primary nav aid then proper training (perhaps inter company) may be required as it does take a bit of getting familiar and 'quick' at using.
  b) See above.
- Mostly operator.
  b) Practice. (By using the simulator mode and reference to manual).
- Learning how to use it.
  b) Better written instruction manual, written in simple English.
- Learning the different functions at the beginning
  b) By reading the user manual properly Its written in American!.
- Understanding heading/track and aircraft position indications.
  b) Better/more briefings on these.
- Trying to understand the instructions, see q
  b) Perhaps not trying to make them so versatile - maybe the designers need more field experience from average pilots as an input to design.
- Uncertain of correct use of functions and knowing all the functions it has. Entering correct latitude and long.
  b) Ground courses, included as part of IR. "Type rating" on different GPS types.

Design
Position (1)
- Mounting it in the when the radio stack is full.
  b) Buy a panel mounted unit. Shift radios to mount in radio stack. It all comes down to $$.

Power (14)
- Not getting power always from a/c therefore running out of battery power.
  b) Better maintenance
- Power loss when operating on rechargeable batteries.
  b) Use alkaline batteries which last longer.
- I left it without a power source for over 20 minutes and scrambled its brain.
  b) Better training.
- Battery life is short.
  b) Much longer battery life. Use GPS for 1 every 15 minute to monitor track.
- Battery packs run out at crucial times.
  b) Using aircraft power source if provided and carrying an ample supply of spares.
- Battery power running out.
  b) Battery life left display.
- Blown fuse in cigarette lighter adapter.
  b) Can't be.
- The batteries going flat mid-flight. (It only happens once!)
  b) Taking spares, cigarette lighter adapter.
- Battery failure when I least needed it!.
  b) Connection to a/c power source with auto switching to internal battery backup should a/c power fail.

- Battery flat without warning.
  b) Power source indicator, battery remaining indicator.
- Very short warning time when batteries about to expire (this was before I had use of a/c internal power (about seconds). Do not know state of batteries.
  b) Have some sort of battery state indicator, longer warning period when about to expire.
- Flat batteries
  b) External power.
- Loss of power with no warning. When running on internal batteries it uses duracells in less then hours.
  b) If the a/c power source isn't functioning the internal source is the only alternative, using a portable high capacity battery would solve the problem.
- Very high battery consumption.
  b) Hard wired to a/c power.

Aerial/Satellite Reception (41)

- Using the internal, portable aerial is not reliable- GPS can 'drop out' without warning due to insufficient satellite reception or strength.
  b) need external aerial installed.
- Very few now- early on you would lose signals but this is not happening now.
- loss or degradation of signal.
  b) external aerial.
- Very rare - poor satellite coverage.
  b) more satellites.
- Waiting for satellites.
- When not aircraft mounted aerial (i.e. external) satellite shadow can be experienced giving poor coverage.
  b) TSO'd models must be a/c mounted with external aerials.
- Low level use and tramping/climbing before all satellites operational - a known problem but ok now.
  b) Problem finished so not worth spending time on - however info on sat pattern times when it could have been used should have been more available.
- Losing satellites.
  b) Different aerial positioning.
- Losing satellites - probably due to aerial position.
- Loss of coverage only.
- Loss of sat data due to an aircraft crash.
  b) Unit was returned for service.
- Loss of satellite signal. Insufficient satellites for D navigation although altitude function is not necessary.
  b) External aerial. More satellites.
- Loss of satellites (due to instrument being hand-held).
  b) fixed antenna.
- Loss of satellites - only once in months
  b) Talk to the pentagon.
- Loss of satellites giving inaccurate information.
- In earlier years satellite availability and selective availability.
  b) Have been rectified by more satellites and service not controlled by military.
- Getting second hand coordinates e.g. one search the coordinates were taken as 168 east when in fact the boat was 168 west which was not discovered until 30 minutes later when the ship gave us an update and said 168W. Fortunately we were just getting airborne and not too much time or money was wasted. Lack of satellites, although not too often lately.
  The tampering with the satellites by whomever! e.g. once early this year on a SAR ex I was handed co-ordinates of a 'target' by another a/c around 11 am. About 2pm when trying to locate said target even with a general description were unable. The spotter plane was called back to the area and directed us to the target. (Most embarrassing) when a/c relocated the target, it was 10 km from the am position. Having discussed this with other pilots they have found the same problems. Usually linked with problems with a war somewhere e.g. an air strike in Bosnia coincided with the above

- Difficult to read in some light conditions.
  b) Design change.
- Hard to read display under certain light conditions, awkward position to read.
  b) Better design, placement of display.
- Display readability.
- Not many
  b) Better display.

Controls (11)

- Like to see pad buttons labeled.
- Too many buttons to push in high workload situations. They aren't that user friendly although they will have to be for TSO approval to do instrument approaches.
  b) Have a switching box sending GPS CTE, GS, CDI etc. info to a HSI/DME/EFIS display similar to INS now.
- Not very user friendly.
  b) Less button pushing.
- When using goto getting 'position saved'.
  b) Add another button.
- Believing it originally, Some inexplicably long periods during a flight when it goes onto DR (usually because PDOP is too high), Overturning the selection (of waypoints) knob during flight or turning that knob too quickly which makes the selection jump right to the end.
- Button size.
  b) Rotary switch.
- Changing quickly from one function to another.
  b) Practice.
- Changing waypoints in flight.
  b) Practical training.
- Compressed multi-function keypad relatively difficult to manipulate in flight. Needs a lot of double checking of entries - a larger panel mounted unit would be easier.
- Difficult to reprogram in turbulence or in IMC conditions flying single pilot IFR easier to tune /select VOR/DME and ADF or ILS.
- Difficulty in obtaining appropriate service via menus or sub menus. Some suffer long periods of 'no track'.
  b) Reduce no. of functions or make sub menus available without so much button pushing. Give short familiaristion courses.

Data Input (5)

- Nil (Other than wrong entry of data - or entry of wrong data) subtle distinction and a rare event anyway.
  b) Care when plotting and entering data.
- Inaccurate data input, reading the time, turning it off (once you know its easy).
  b) training, training.
- Input error, using wrong waypoint put to much reliance in its use, fault in antenna which made system u/s in flight.
  b) Double checking, cross checking with maps, education into common errors people make.
- Inputted a lat./long from an airfield chart that was wrong on the chart (overseas).
  b) Ensure all aeronautical info is correct.
- years ago Kaikoura had wrong co-ordinates in VFG.

Functions/Software/Complexity (15)

- Initially mastering the search sequence.
  b) Good basic instruction initially.
- The GPS gives a bearing 'to' station and CDI is in nautical miles not degrees. VOR uses radials or bearing 'from'.
  b) Changing user manual to explain differences between navigation with reference to GPS and VOR.
- Occasional loss of position updating. Also not being able to edit a flight planned waypoint.

- Present position can only be determined by reference to e.g. XTE and Distance to Go also it is not easy to enter a waypoint or route to an alternate destination.
  b) Perhaps simultaneous display of distance to two waypoints would assist position fixing.
- Programming.
  b) Better manuals, training.
- RTE function.
  b) Talking to an expert.
- Selecting user waypoint.
  b) More practice.
- Renaming a waypoint.
  b) By being a little more aware of what mode I am in before pushing buttons.
- Remembering how to bring up the different functions.
  b) More use.
- Keeping current with little used functions.
  b) Better presentation of functions and switching from one to another.
-) Cannot fly an offset track (i.e. . nm right) for additional traffic separation (particularly international).) Ref. earlier for database prob.) Our GPS does not cater for a 'turning circle', desirable for mil low level operations.
  b)software upgrade.
- At times Magellan 'locks up' and when it is turned off at power source and on again ' user waypoints' are lost.
  b) Don't know.
- GPS unit lost its bearings and sent its whole database into northern hemisphere.
  b) Re-establish correct date/time and present position - variation.
- Just getting used to it. You set up a flight plan or route plan and then push the wrong button. Back to square one.
  b) Practice.
- Nav section, efficiently accessing the activating and storing of the waypoints for to, next and from.
  b) Knowledge of confident locality of waypoints and understanding of preprogramming the Trimble for the flight.

Database (5)
- Airways Corp. keeps changing DVORS for CVORS, putting database out of data.
  b) Spending money for database updates.
- Keeping it updated
  b) Regular disks to be inserted.
- Removing data.
  b) More study, school of instruction with real quality teacher.
- Over large database.
  b) NZ only database or selection.
- Local (Australasia Sth Pacific database) discontinued and only International database available now.
  b) Reinstitute regional databases so as to remove the multiple identifiers to a manageable level. Outside of North America II Morrow now offer only the International data card which includes airports (freqs. available runways, lat./long, fuel availability, lighting ILS) VOR's, NDB's and Intersections (reporting points). With the loss of the regional data card (Australia/ Sth Pacific) I find we have multiple listings for many Nav aids - this is particularly apparent in the NDB data base. Example : Australia/ Sth Pacific database no longer available. The Wellington TMA contains the following NDB's with numbers in brackets showing the entries. CC(2) FY(1) BM(2) PM(1) PP(1) TY(1) WB(1) WN(1) -[MS NDB not listed] Listed NDB's = 8. Possible selections = 10. Same area with International database. CC(9) FY(5) BM(8) PM(2) PP(3) TY(6) WB(3) WN(4) MS(12). Listed NDB's = 9. Possible selections = 52. This makes flight planning a real chore. In flight use nearest 10 VOR/NDB/Intersections for Nav.

Behaviour (6)
- Once you are used to using the GPS there are little if any problems that I can see apart from the new pilot relying on them from day rather then getting a good grounding in nav tracking and map reading.

- Acting as F/O, Captain not preparing (flight planning) fuel time intervals on unknown route.
  b) Do not over sell GPS. Basics are basics. A plan is the best place to start.
- It tends to use valuable look out time.
- Using it too much and not cross checking and satellites are lost and GPS goes off-line.
  b) Always have a backup.
- Trying to get a new waypoint while in flight ends up taking mind off flying and keeping a lookout. Loss of satellites when approaching a new destination very annoying.
  b) Set up destinations prior to departure or have a copilot/navigator to do this while in flight (this is the option we do).
- Turbulence, misinformation with co-ordinates of waypoints must always double check.
  b) Care with information setup.

Misc. (4)

- Aerodrome and nav aids have differing long and lats but once aware of this situation it is not a real problem.
- None that good pre flight planning can't avoid.
- None while flying. Plenty while sailing using coupled chart plotter. A number of times plotter shows us on dry land. However after anchoring, plot comes correct after about 10 minutes.
  b) Problem is with the electronic map. Take very much care when using electronic maps.
- Nil (Other than wrong entry of data - or entry of wrong data) subtle distinction and a rare event anyway.
  b) Care when plotting and entering data.

Do you have any examples of hazards or traps that may catch people out using GPS?

User competence (4)

- Changing flight due weather then not being current enough to change the GPS.
- A lack of knowledge or total reliance on GPS without backups.
- Being unfamiliar with the unit functions.
- Heaps, poor knowledge.

Data input, output, monitoring, checking (58)

- Fixation on the GPS to the exclusion of other nav equipment. Rubbish in rubbish out.
- Using it too much and not cross-checking.
- Inputting incorrect lat. and longs
- Using wrong co-ordinates and not cross referencing in flight with maps and compass if VFR.
- Using wrong fix.
- Waypoint incorrectly entered. Must always double check long and lat. (Rubbish in you get rubbish back).
- Watching someone hasn't changed something from last time you used it. (This has happened but due to nature of use has no safety consequences).
- Where the GPS has a facility to set the variation manually, this can make large differences to tracks.
- Wrong co-ordinates put in. Do not forget hills get in the way.
- Wrong lat. and long.
- Wrong waypoint info is the greatest hazard. Not using charts to co-ordinate track with airspace requirements.
- Yes if inputting own coordinates double check. If user map reading is poor the user would not pick up the problem until too late.
- A) Entering wrong 'to'. B) I suspect that altitude information is not very accurate.
- Always double check! (As per any other procedure i.e. tune identify).
- Awareness of aerodrome and nav aid lat./long differences.
- Co-ordinates printed in degrees/decimals or deg/min./sec's. Co-ords different on IFR charts to comm. freq. pages in AIP.
- Check the scales of CDI etc.
- Checking of data inputted before flight.
- Data lat./long out marginally - it's a real trap.
- Easier to put in coordinates.

- Entering incorrect waypoint co-ordinates and blindly believing the GPS.
- Entering wrong compass cardinal points i.e. as stated earlier 'E' for 'W' ('N' for 'S' as I also use the unit for flying in the Northern Hemisphere).
- Entering wrong long and lat. for waypoints.
- Garbage in garbage out.
- Heaps, poor knowledge, wrong waypoints & designators,.
- I am very concerned that user manual does not offer any suggestions or recommendations regarding cross checking of entries in user database nor for that matter normal flight planning and navigation.
- I have heard of an a/c carrying out an NDB app using GPS as primary (NDB u/s - bombed out!) but having an incorrect lat./long for the NDB. Fortunately this was discovered by and a/c on the ground who saw the a/c going in the wrong direction.
- If entering info manually check, check and recheck.
- Incorrect information entered. If a lot of information presented on one page takes time to comprehend - especially airborne.
- Incorrect lat. and long programming.
- Incorrect or mistaken values set e.g. kilometers instead of nautical miles, true instead of magnetic bearings etc.
- Input correct time code and distance (i.e. kmph, or knots).
- Inputting wrong data, either when making user waypoint or selecting incorrect waypoint i.e. more than 1 NDB or VOR with same IDENT letters.
- Old data in database.
- Make certain that correct information is created into the database. Make certain that 3 satellites or more are captured. Do not use height information displayed. In VFR conditions always cross-check information with map and also do rough calculations with regards to time to go etc.
- Operator data input.
- Lat. and long in as much as north and south getting swapped as does east and west.
- Make sure your lat./long are correct.
- Misinformation keyed in.
- Making sure you enter south & east after entering lat. and longs. Most makes tend to revert to north and east after being reset. Makes a big difference to the distance to point.
- People not recognising failure in a GPS in which inaccurate information coming in to screen.
- Pilot input errors.
- Problems of programming i.e. confusing true and magnetic. Caution in using them i.e. using wrong mode.
- Programming incorrect co-ordinates.
- Single pilots programming data and then using without checking or proving. Flying instrument approaches at the end of a GPS route. Route should be cleared prior to the approach and go to final navaid entered. Otherwise on missed approach GPS continues to fly the route.
- The estimated time enroute (ETE) gives instantaneous ETE and cannot be used to give a useful ETA until established in the cruise.
- The major trap is entering incorrect lat./longs also the possibility of risk taking in bad weather relying on GPS.
- The only hazards I can see are errors on inputting long & lat. for user waypoints.
- Not ensuring initial entries are accurate and cross referred to prove their accuracy and validity.
- Not cross checking information from another source - basic nav procedure.
- No positive IDENT of destination selected as with VOR/ADF, mistakes could be made with selection of waypoints e.g. AA or AR.
- Using CDI display which replaces waypoint name and not knowing which leg they are on.
- When a choice of Nav info from GPS or VOR for CDI on HSI there is little to show which you are using.
- When flying 180 of entered track, the tracking indicates in reverse sense (similar to a VOR).
- On my GPS the bearing from or to a waypoint, or beacon nav-aid is back to front have to remember to use the reciprocal.
- On Trimble - being able to select between to and from can lead to pilots (who are not monitoring distance) fly away instead of to a waypoint.

- Should always fly to a waypoint rather than away from it - this should not prevent you from checking distance from a waypoint though.
- The odd/even display is not set for NZ conditions. Track 0-179 indicates odd (should be 270-89). 180-359 indicate odd (should be 90-269). Loss of satellites can mean you may not have any fixes for considerable time.

Lookout, Scan, Terrain (19)

- Reduced lookout.
- 'Lookout' one has to discipline oneself not to become engrossed in GPS at expense of keeping a good lookout.
- Only that it is easy to become preoccupied playing with the buttons - distracts from lookout and visual navigation.
- When VFR not looking out the window.
- First time users should be aware that a lot of time is spent with head down trying to sort out functions.
- Not enough time 'head up' not keeping a good look out and visual position references.
- Fixating on the unit only!
- Fixation on the GPS to the exclusion of other nav equipment. Overuse of GPS for VFR work. See and avoid is still important.
- Make sure they and myself keep their heads out of the cockpit.
- Can become engrossed and not keep good lookout.
- Less emphasis on lookout, lack of normal nav technique and position whereabouts when GPS stops working.
- Lack of lookout and terrain clearance.
- Height of terrain. Keep your eyes outside.
- Terrain clearance when insufficient waypoints are used.
- En route terrain.
- Lack of awareness of terrain being crossed/ approached i.e. hills, lack of airspace knowledge.
- Must combine it with map reading. It does not tell you about obstructions.
- Charts give the height of terrain ahead - GPS does not.
- Direct track info gives no terrain info - must refer elsewhere for MSA's etc. Should provide a national database on disc.

Situation awareness, Decision making, judgement, Overdependence, Weather, Risk Taking (35)

- Loss of situational awareness whilst VFR due to sole reliance on GPS as navigational resource.
- Blindly accepting information without thinking 'does that sound about right?'.
- Not planning before flight and then losing GPS cover in flight. Not cross-checking with maps, input wrong lat. and long or waypoint. Flying in weather conditions that they would not normally fly in without GPS.
- Not being aware of your position on the charts as total reliance can be placed on the GPS navigational data.
- Following the GPS to the letter and therefore flying into restricted areas or controlled airspace without knowing.
- Flying the GPS and not the aircraft in marginal conditions. Temptation to spend more time above 7/ -8/8 cloud!! No letdown!! at destination. Not programming control areas in and thus infringing same.
- Encouraging VFR pilots to get on top of cloud. GPS doesn't help with basic instrument flying skill or experience.
- Aware of incidents where GPS may have increased risk taking - VFR over top - into marginal wx - (e.g.. Protech crash).
- Persons going 'over the top' of cloud base in the hope that at destination there will be a break large enough to descend through.
- Going over 8/8 cloud and losing GPS when using it as primary nav.
- Relying on GPS in bad weather - VFR pilots may become complacent.
- Do not depend on GPS for sole navigation input power can fail at a critical time (In mountains under overcast).

- Dependence on GPS to extent whereby they will continue in flying conditions in which they otherwise may not have.
- I Know of instances when a friend has flown in weather he would not of before acquiring his GPS.
- Relying on GPS too much - not enough time 'head up' not keeping a good look out and visual position references. Temptation to go IMC on GPS as primary nav.
- The possibility of risk taking in bad weather relying on GPS.
- Complacency and absolute faith the thing will always be accurate and available.
- Complacency!
- Total reliance on GPS without backups.
- Easy to rely on it too much. It seems many VFR pilots would not be without it. One wonders if this is at the cost of basic nav skills.
- GPS is so good that you have to force yourself to remember it could fail, and avoid depending on it totally. If not, could get into situation where its failure could be serious.
- It should be used in conjunction with, not alone.
- Pilot becoming preoccupied with GPS during VFR. Attempting GPS primary IFR with no IFR training. Being in a GPS dependent situation and losing coverage.
- Over reliance on GPS - not cross-checking with maps.
- Over-reliance - forget basic nav concepts. Over-use - lowered awareness of CTA and terrain.
- One must use in conjunction with conventional equip until familiar with use.
- Relying on it solely e.g. when it's not position updating!
- Relying on it too much. Don't nav and get lost.
- VFR pilots flying only on GPS for nav.
- VFR can become so reliant on it that when it goes off (poor signal) you can be lost.
- Using the GPS as a sole aid. Can be caught out having to revert to conventional aids.
- Too much reliance on GPS not enough lookout! or mapwork.
- Too confident and no cross checking.
- The main hazard would be becoming totally reliant on GPS and not using charts and nav computer as a backup or occasional check e.g. charts give the height of terrain ahead - GPS does not.
- Don't rely on accurate altitude information.

System integrity (17)

- No warning or indication that selective availability may be being applied. Altitude on GPS not necessarily the same as (QNH, QFE etc.) what is shown on altimeter. Not yet IFR approved in NZ.
- Make certain that correct information is created into the database. Make certain that 3 satellites or more are captured.
- Need backup in case of failure of GPS.
- GPS going off-line when loses satellites.
- Loss of satellites can mean you may not have any fixes for considerable time.
- Using the GPS in simulator mode. Did that once - only once- some of the information had me confused - like groundspeed etc. but the unit still functioned ok on heading etc.
- Ensure correct heading is set, to check track against compass heading. Possible interference with NAV-COMM equipment (e.g. harmonic interference). Remote cable may interfere with other controls or switches.
- Yes looking down at the yoke mounted models.
- One ferry flight Turkey-NZ lost GPS indications - don't rely 100% on GPS.
- The loss of satellites.
- Internal aerial unreliable, particularly in different aircraft types where good aerial viewing of satellites not easily available.
- Losing sat signals especially low level.
- Losing satellite contact which does not show track line on moving map or any other information.
- Flat batteries, poor antenna location.
- Make sure battery power is adequate. I fell into the trap of entering lat. and long on low bat power for the next days flight leg and the co-ordinates came out wrong. (The user manual does warn you not to operate on low battery power).
- Battery operation only could lead people into problems therefore I use a/c power where possible.
- Danger of traffic 'congestion' at GPS waypoints

Appendix L: Conference papers and publications from this study

Nendick, M. & St. George, R. (1995). Human Factors aspects of Global Positioning Systems (GPS) Equipment: A Study with New Zealand Pilots. Paper presented to the *Eighth International Symposium on Aviation Psychology*, Columbus, Ohio.

Nendick, M. (1995). Human Factors aspects of Global Positioning Systems (GPS) Equipment: Pilot Training Implications for Flight Safety. Paper presented to the *International Symposium on Aviation Human Factors*, Auckland.

Nendick, M. (1995). Global Positioning System (GPS): Human Factors aspects for General Aviation Pilots. *Association of Aviation Psychologists Bulletin*.

Nendick, M. & St. George, R. (1995). GPS: Developing a Human Factors Training course for pilots. Paper presented to the *Third Australian Aviation Psychology Symposium*, Sydney.