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Reducing Cannon Plug Connector Pin Selection Time and Errors through Enhanced Data Presentation Methods

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THESIS

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THESIS

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Bob Webb

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Abstract

The purpose of this research is to investigate the effects of data presentation methods on technician performance when the procedures are presented on a monocular, head-mounted display (HMD) in a static maintenance environment. This research used two different methods to present the maintenance task data to the technicians. The first method showed the task as it is typically described in standard technical manuals. It described the task to perform and provided a basic picture of the cannon plug to be tested (unenhanced). The second method provided the same information as the first, but it also modified the information by providing visual cues as to which pins were to be selected and connected (enhanced).

United States Air Force avionics maintenance technicians stationed at Barksdale Air Force Base, Louisiana were the test participants in this study. Measurements included task completion time, task error rate, and technician self reports on the HMD usability. The technicians indicated that HMDs could be a useful tool in the performance of their maintenance duties. The data collected during this study indicates that the technicians performed the tasks quicker and committed fewer errors when they used the enhanced graphical data presentation method to perform the experimental tasks.

REDUCING CANNON PLUG CONNECTOR PIN SELECTION TIME AND ERRORS THROUGH ENHANCED DATA PRESENTATION METHODS

I. Introduction

Background

Since the early 1980s the Department of Defense (DoD) and commercial industry have been moving to digitize, computerize, and automate the technical manuals that are used by maintenance technicians to troubleshoot, repair, inspect, service, and maintain weapon systems. Automated maintenance aids -- maintenance aids that are based on computer technology, and integrated maintenance aids -- that provide interactive system tests and access to required technical information for troubleshooting and repair, are beginning to be fielded more frequently.

Maintenance is continually performed in less than ideal conditions. Technicians are often working out in the hot/cold, wet/snowy weather, within confined places, dealing with limited part accessibility, and needing both hands to perform a task. Any automated or integrated maintenance aid must be able to perform in these conditions in order for it to be a true asset to the technician. Maintainability and integrated maintenance are being incorporated into new weapon systems procurements. Many systems currently fielded are being investigated to see if they can be retrofitted with more automated maintenance aids (Kolleck, Booz, Allen, & Hamilton, 1994).

Research has shown that automated maintenance aids improve maintenance technician troubleshooting performance -- not only in problem identification, but also in task completion times and in reduced maintenance costs (Schroeder, Smith, Bursch, & Meisner, 1992; Thomas, 1995). Knowing that automation and computerization can improve performance is one matter, but getting it out on the flightline or any other place where the maintenance is being performed, is quite another.

Armstrong Laboratory at Wright-Patterson AFB, Ohio has been conducting research to develop and evaluate technology for an Integrated Maintenance Information System (IMIS) since the 1970s (Thomas, 1995). Results from the IMIS test and evaluation process has provided the promise of reducing maintenance technician troubleshooting errors through the use of computerized maintenance data presentation methods (Thomas, 1995). These presentations are computerized versions of the technical manuals, troubleshooting trees, and parts diagrams used by technicians.

Aircraft maintenance technicians were tested to see if computerized data presentation methods would improve their performance by reducing the time to complete specific tasks or reducing error rates (completing the wrong task or making the wrong troubleshooting decision). The tests showed that the technician error rate was reduced using the computerized data presentation method. The largest source of observed error came from the improper use of test equipment, with selecting the wrong cannon plug pin being the largest contributor (Thomas, 1995). Improper cannon plug pin identification can be a serious problem, misapplication of test leads can cause thousands of dollars of damage by improperly routing voltage to the wrong circuit (Shepherd, 1990).

Reducing technician error rates in this area can thus save time in troubleshooting and money in replacement parts. In this era of reduced budgets and reductions in force, any affordable technological advantage that can be utilized to improve the performance of maintenance technicians should be pursued. Improving performance reduces the troubleshooting time required to return equipment (aircraft, ships, vehicles, etc.) back to fully mission capable status. Quicker turnaround means that the equipment is capable of performing its designed combat function more often.

Automation and integration can also be used to train technicians. Computers can be used to simulate a real system in the training environment. Training technicians on simulators allows them to make mistakes and learn without damaging the real system. Thereby saving money in procurement of training assets and repair costs, while still providing the needed training for the maintenance personnel.

Automated and integrated training, troubleshooting, and repair aids require another important ingredient -- the ability to be used in the "real world." That is, they need to perform where technicians work, and they must function as they do in the sterile training environment. In the Air Force's case, one example would be the flightline. Flightline aircraft maintenance technicians must be able to use their equipment in any situation, under any condition.

Portable head-mounted displays (HMDs) have been studied to see if they can provide the portability, reliability, flexibility, and durability required for flightline maintenance operations (Masquelier, 1991; Friend and Grinstead, 1992). Figure 1 depicts technicians wearing an HMD while performing maintenance tasks. Friend and Grinstead (1992) did a comparative study between a portable flat screen laptop computer and an HMD. The conclusions of their study indicate that technicians performing tasks with data displayed on the HMD generally performed better than their counterparts using the flat screen (Friend and Grinstead, 1992).

Figure 1: Maintenance Technicians Wearing an HMD

The present research expanded on Friend and Grinstead's (1992) study and Armstrong Laboratory's cannon plug pin selection error problem identification during the IMIS field test by investigating the use of HMD technology in reducing cannon plug pin selection errors through the use of enhanced graphical data presentation methods. Enhanced graphics intends to improve the standard presentation and consists of highlights and visual cues as to the cannon plug pins in question. Figure 2 contains examples of both the unenhanced and enhanced presentation methods for the 13 pin cannon plug used in this thesis.

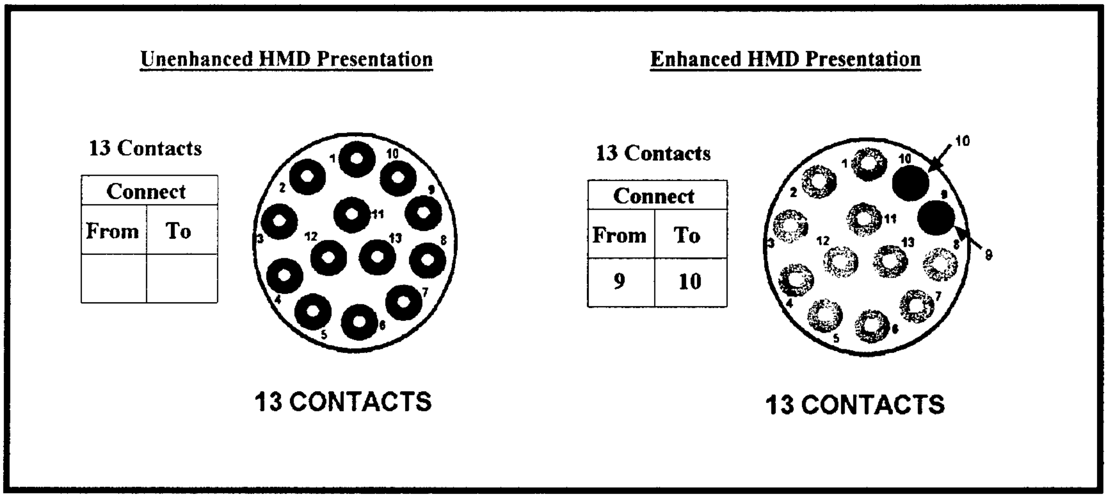


Figure 2: Unenhanced and Enhanced HMD Presentation Methods for the 13 Pin Cannon Plug

An HMD was used to present two different graphical representations for the same cannon plug to technicians to see if enhanced graphics could be used to help technicians properly identify pins on the cannon plug and reduce pin selection errors made by technicians. The number of cannon plug pins was also investigated to see if the number of pins would effect technician performance.

Thesis Statement

HMDs are currently used to provide automated technical data to maintenance technicians. Much of this data is simply digitized representations of the paper products currently being used. The paper data is scanned and imported into computerized versions of the original technical data, which enables large amounts of data to be readily available to the maintenance technicians.

Research has shown that the computer version of the technical data can reduce errors made by maintenance technicians; however, errors are still made in selecting cannon plug pins. The primary objective of this thesis research was to determine if an enhanced cannon plug presentation method, by means of a head mounted display, would reduce maintenance technician's cannon plug pin selection time and errors.

Research Hypotheses

The overall research hypothesis is that graphically enhanced data presentations will improve technician cannon plug pin selection and connection task performance. The following hypotheses detail how technician performance is defined:

1. Fewer cannon plug pin connection errors are made using the graphically enhanced presentation on the HMD than the unenhanced presentation.

2. Pin selection/connection takes less time using the graphically enhanced presentation method than the unenhanced presentation.

3. Cannon plugs with fewer pins will have fewer connection errors than cannon plugs with many pins.

4. Cannon plugs with fewer pins will take less time to complete the task than cannon plugs with many pins.

5. For enhanced presentations, there is no statistically significant difference in time to complete the tasks between cannon plugs with many and few pins.

6. For unenhanced presentations, cannon plugs with few pins will take less time to complete the tasks than cannon plugs with many pins.

7. For enhanced presentations, there is no statistically significant difference in the number of task completion errors between cannon plugs with many and few pins.

8. For unenhanced presentations, cannon plugs with few pins will have less errors in task completion than cannon plugs with many pins.

Test Equipment and Scope

Armstrong Laboratory provided the hardware and software for use in this research effort. They have conducted research with the HMD system and software since 1992 and have the system fully integrated. The HMD eyepiece had a green monochrome 640 x 480 pixel resolution VGA screen and was made by Kopin™. The graphical data presentation was programmed in Visual Basic™ software language.

The five cannon plug connector breakout boxes used in this research were also supplied by Armstrong Laboratory. Figure 3 is a picture of the four break-out boxes containing the four different cannon plug types, which have 12 to 79 pins, that are used as the test instruments. The pins are visually referenced by either numbers or letters printed on the plug mating surface. The wide variance in pin numbers was selected to test the effect of the increased number of cannon plug pins on the maintenance technician error rate. The fifth cannon plug connector breakout box, shown in Figure 4, is rectangular and is used for training and HMD orientation.

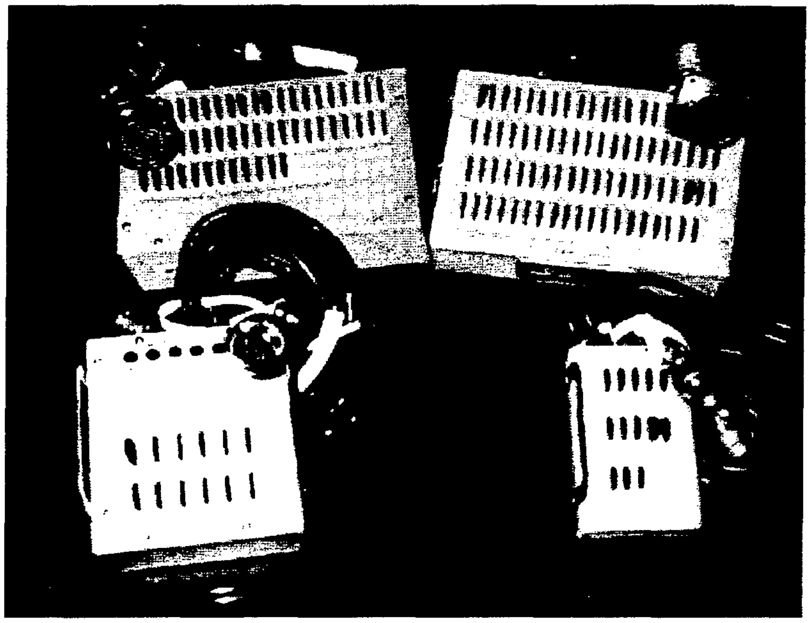


Figure 3: Picture of Breakout Boxes Used in this Research

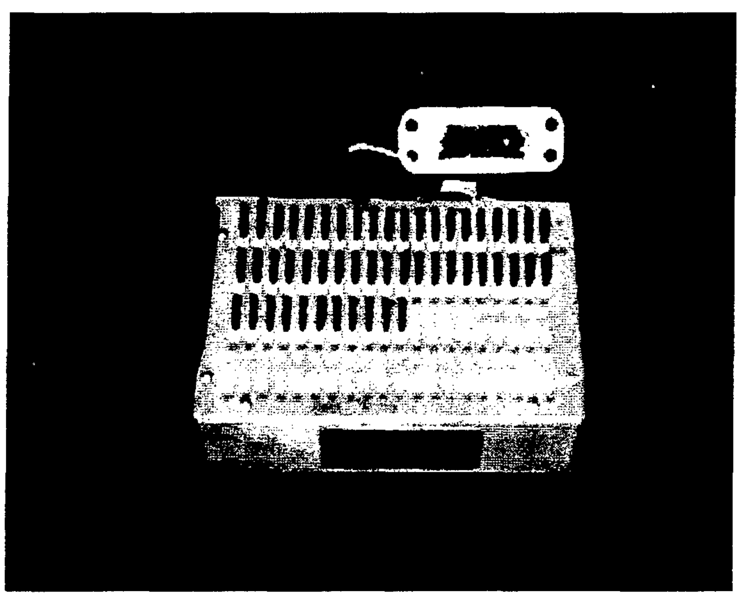


Figure 4: Picture of Practice Breakout Box Used in this Research

The technical manual schematics of the cannon plugs were programmed into Visual Basic™ software for the baseline test and then augmented through visual queues and contrast schemes for the enhanced test. Each maintenance technician was required to complete sixteen total tasks, four on each cannon plug. Half of the tasks were completed using the unenhanced graphical presentation and half used the enhanced presentation method. This test method scheme was developed using a randomized block design that is discussed in Chapter Three of this study.

General Approach

A literature review was conducted to identify the relevant aspects of this research effort. Maintenance practices, computerized data presentation methods (to include head mounted display devices), monochrome displays, human factors in visual acuity and fixation, and experimental design research streams were investigated. From the literature review, the experimental method and data analysis technique for this thesis were developed. Additionally, the applicability to previous and current research and the significance to the Air Force was established.

The experimental sampling method was designed around the test equipment available during this research effort. The entire system was assembled and the experimental test method and procedures were tested and validated through a pre-test prior to gathering the test data in the field. Data was then gathered from an active field unit. The data was then analyzed and tested against the thesis research objective of this study -- to see if the enhanced data presentation method does, in fact, reduce the cannon plug pin identification and selection time and error rate. The results of this analysis are presented in Chapter Five of this study.

Summary

This thesis utilized and built upon research previously performed by Armstrong Laboratory and Master's candidates from the Air Force Institute of Technology (AFIT). Investigating the benefits of enhanced graphics and head-mounted displays logically follows field observations resulting from several studies. These studies demonstrated the reduction of errors using computerized maintenance aids verses traditional paper technical references, and the improved performance obtained from using HMDs over flat screen portable computers.

Thesis Overview

This thesis is divided into five chapters. The first chapter canvasses the general background information on this thesis' research focus, method, and questions. Chapter Two comprises a literature review on the current state of computer enhanced data presentation methods and their applicability to this thesis. Chapter Three outlines the research methodology used. Chapter Four is the analysis of the data that was obtained through the methods described in Chapter Three. Chapter Five, discusses the results of the analysis of the data and provides recommendations for future research.

II. Literature Review

Overview

This chapter comprises a literature review of previous head mounted display (HMD) data presentation method studies, ways to optimize the presented data, and HMD applicability to military maintenance operations. The literature review incorporates commercial, professional, and trade journals, Department of Defense technical reports, the World Wide Web, and previous AFIT theses.

Armstrong Laboratory requested that the monocular head-mounted display from Kopin™ be used as the display device for presenting the experimental information to the test subjects. Because of this request, only monocular HMD designs were investigated in this literature review. The information collected was limited, but did include information on ways to improve data presentation on computer screens and some advantages and disadvantages in the use of an HMD.

Military Maintenance Applications

Military maintenance technicians face many unique obstacles to performing their assigned duties that their civilian counterparts do not. Deployments, unique settings, remote locations, and a wide variety of equipment are but a few examples of that difference. Any maintenance aids and equipment that are used by military maintenance technicians must be able to perform in many imaginable situations and must be highly reliable.

Automated maintenance aids are becoming commonplace in the military maintenance community. Maintenance Error Decision Aids (MEDA), Avionics Troubleshooting Systems (ATS), Flight Control Maintenance Diagnostic Systems (FCMDS), Aviation Diagnostics and Maintenance (ADAM) systems, and Integrated Maintenance Information Systems (IMIS) are but a few of the computer-based aircraft maintenance aids that are beginning to surface on Air Force flightlines (Hibit and Marx, 1994; Gulick and Kell, 1993; Schroeder, Smith, Bursch, and Meisner, 1992; Le Beau, et. al., 1991; Thomas, 1995).

These systems offer the power and speed of computer-driven maintenance tools with the knowledge that an expert system brings. Expert systems provide any maintenance technician the detailed system knowledge usually only obtainable through years of experience. Expert systems can enable inexperienced and uncertain technicians the system knowledge to operate as if they were experienced. These systems also provide reminders and double-checks to more experienced technicians when they encounter something that they are uncertain about in the system.

Research conducted by Friend and Grinstead (1992) indicates that HMDs improve aircraft maintenance technician inspection task performance over the current flat-screen presentations that are available. HMDs can be incorporated into aircraft maintenance training to improve technician performance from the start of their career. The days of extensively training maintenance technicians and investing years before they can be allowed to perform maintenance tasks can be in the past (Basta, 1995). Computer-based training using HMDs can enable first-time technicians to perform like veterans on the flightline.

Previous HMD Studies

Through extensive literature examination, this researcher has found only three evaluations that previously performed an assessment of the applicability of HMD technology in a maintenance environment. The first evaluation took place in 1990, with the report released in 1991, by the General Dynamics Electronics Division. General Dynamics conducted a comparative evaluation of HMD and flat-screen computer technology. F-16 aircraft maintenance technicians were asked to compare HMDs and hand-held flat-screen computers while performing bench checks on equipment. The technicians completed a rating scale and remarked on open-ended questions (Edwards Evaluation Report, 1991).

The General Dynamics study resulted in the following conclusions:

1. Both HMD and flat-screens are suitable for displaying technical data in a static environment. However, more technicians indicated a preference for using the flat-screen display device over the HMD.

2. Technician display presentation method preference is dependent on the task they are performing. Technicians indicated that in performing tasks that require their hands to be free, such as situations where tools are in both hands **and** the technical data must be in close proximity, HMDs are the better choice.

A flaw in the study may have been that the test participants did not receive enough time to adjust to wearing and using a bulky and heavy (over 10 pounds) HMD. Advancements in technology enabled the use of an HMD that weighed less than one pound in this thesis.

Because technicians indicated the HMD would be preferential in certain situations, display presentation method may be task dependent.

The results of the General Dynamics evaluation helped to identify the maintenance tasks to be performed and to highlight the need to establish the HMD training conducted for this thesis. The present research has test subjects perform cannon plug pin selection and connection tasks that require their hands to be free. Technicians have to hold the cannon plugs and test adapters simultaneously, they have no free hand to hold the required technical data. Technicians also conduct familiarization training on the HMD and complete practice tasks before the collection of the actual test data.

Masquelier (1991) conducted the second study that addressed HMD use in a static maintenance environment. She had F-16 aircraft maintenance technicians use an HMD and a flat-screen computer to display the technical information for routine intermediate level maintenance bench-top troubleshooting tasks. Masquelier (1991) found no *overall* statistically significant results in the difference in performance between the group that used the HMD and the group that used the flat-screen display device to display the technical information. However, she did find that the aircraft maintenance technicians with 'experience' statistically performed better, took less time, and made fewer mistakes, than those technicians with limited 'experience.' Masquelier (1991) defined experience as those technicians with more than one year of actual hands-on system maintenance time.

The findings of improved performance for 'experienced' maintenance technicians found in Masquelier's (1991) study supports assertions made by Heleander (1988) that:

> Users who have acquired extensive knowledge and skill related to their job might be expected to use a computer system on the job more effectively than users with little domain specific knowledge. (Heleander, 1988)

The Masquelier (1991) and Heleander (1988) studies were important to this thesis in that they supported the elimination of the technician experience variable from the study.

This thesis was limited to 'experienced' technicians for two main reasons. One reason was to eliminate a potentially confounding variable. The other was that 'experienced' technicians are familiar with the task being performed and could provide a more in-depth analysis of the HMD. Inexperienced technicians would be trying to figure out both the maintenance task and the HMD during the experiment, and they may not have been able to provide as insightful feedback as the 'experienced' technicians.

Friend and Grinstead (1992) conducted a third study that used an HMD in a maintenance environment. They looked at the display of aircraft maintenance technical data on an HMD and flat-screen display in a flightline maintenance environment. An important difference between Friend and Grinstead's (1992) and Masquelier's (1991) studies is that technicians in Friend and Grinstead's (1992) study conducted tasks on the flightline, in normal working conditions. A-7D aircraft maintenance technicians completed an operational checkout task using an HMD and a flat-screen monitor to display the maintenance technical data. The technicians are also divided into 'experienced' and 'inexperienced' groups.

Friend and Grinstead (1992) found that technicians using the HMD correctly completed the task quicker than the technicians that used the flat-screen display. In addition, the technicians using the HMD made fewer errors than the technicians using the flat-screen display. Furthermore, the 'experienced' technicians outperformed the 'inexperienced' technicians in both task completion time and errors committed (Friend and Grinstead, 1992). The results of Friend and Grinstead's (1992) study supported the use of only 'experienced' technicians in this thesis.

HMD Disadvantages and Advantages

Most HMD studies have been conducted in dynamic environments -- in aircraft cockpits or aircraft simulators -- and have identified several disadvantages and advantages in their use over traditional flat-screen displays. The primary disadvantages are the wearer side effects that often accompany the prolonged use of HMDs. HMD advantages are experienced in improved user mobility and increased user task effectiveness as measured in increased performance and reduced task completion time.

HMD Disadvantages. The side effects experienced from prolonged HMD use include retinal rivalry, reduced visual resolution, depth perception difficulty, limited field of view, and increased eye stress and fatigue (Rash and Martin, 1988; Hale and Piccione, 1990; Haworth and Newman, 1993; Kotulak and Morse, 1995). Retinal rivalry is the ability to selectively switch back and forth between the two images being presented in separate eyes (Rash and Martin, 1988). This ability is important for the use of a monocular HMD in which the wearer must do exactly that, switch between the HMD display in one eye and the task being performed in the other.

Visual resolution, depth perception, and field of view are all impacted by having the HMD directly in front of one eye and nothing in front of the other. Newer adjustable HMDs can be physically adjusted to allow the wearer to "look through" it as if it were not there (Haworth and Newman, 1993; Kotulak and Morse, 1995). Adjusting the HMD may improve some effects, but it often leads to others. Eye strain and fatigue often accompany long-term use of HMDs and are even more prevalent in the "look through" designs (Hale and Piccione, 1990). These factors are also often compounded by the effect on the wearer's depth perception that accompanies HMD use (Hale and Piccione, 1990).

In dynamic environments, HMD wearers must not only adjust to having a display screen directly in front of one eye, but they must also continue to monitor their continually changing surroundings. Attention is constantly shifted between external stimuli and the data presented on the HMD screen. As the wearer becomes tired their eyes are less able to adjust as quickly and the problems can become severe (Kotulak and Morse, 1995).

The General Dynamics (1991), Masquelier (1991), and Friend and Grinstead (1992) studies tested the HMD in more static environments. These studies indicated that users did experience a slight degree of eye strain from not being use to wearing and using the HMD. Participants also indicated that they had some interference between the HMD display and task object on which they were trying to focus. The test participants indicating that they initially had these problems, also indicated that after they became accustomed to wearing the HMD they were able to eliminate these problems.

None of the studies indicated what percentage of the participants experienced these difficulties. The coverage of these problems in the reports hinted that the actual problems were minor and relatively few test subjects had them. This research effort also asked its test subjects if they experienced any visual problems during or after wearing the HMD.

HMD Advantages. The basic advantages of HMDs are that they are light, compact, inexpensive, and more rugged than typical flat-panel displays. When attached to a portable, wearable computer system, the HMD enables complete user mobility. This mobility allows the user to directly interact with their environment while using the computer and HMD as a task performance aiding device (Quill, Kancler, & Masquelier, 1995). Mobility provides distinct advantages in a maintenance environment where technicians must be able to access tools, test equipment, parts, and read technical data simultaneously.

Additionally, as discussed previously, data displayed on HMDs improve technician task performance, task completion time, and errors made, over using paper manuals or flat-screen displays. Improving technician performance has many advantages. As discussed by Ebling (1997) and Langford (1995), reduced maintenance time increases equipment availability. Technicians are also able to be more efficient and accomplish more during a normal work shift. Accomplishing tasks quicker and making technicians more efficient may enable the reduction in total manpower requirements without over stressing an already limited maintenance manpower pool.

Equipment costs are reduced because the cost of labor is reduced resulting in a total life cycle cost reduction for the system. Cost reduction is the key to a system's survival in this time of budget cuts and force reductions. If the cost to maintain a system can be reduced, it can enable the military to absorb possible future budget cuts without sacrificing maintenance effectiveness. The cost savings could also be funneled into other needed areas. Either way, the cost savings can be beneficial to the entire military.

As shown in the Raaijmakers and Verduyn (1996) study, technicians with relatively little training can be as effective as experienced technicians when presented with maintenance aids that enable system understanding and comprehensive data presentation for task performance. HMDs can be a part of that system. These types of systems can reduce the skill level required for the maintenance technician working on a system. Reduced skill relates to reduced training which equates to less cost to prepare maintenance technicians.

Technical Data Presentation

Computer Screen Design. The studies cited in the previous sub-section, all used 'simple' technical data presentation methods. Much of the technical data presented to the maintenance technicians are simply digitized representations of the paper products currently being used or simple textual troubleshooting flow charts. The paper data is scanned and imported into computerized versions of the original technical data, which enables large amounts of data to be readily available to the maintenance technicians.

Previous research established that the computerized version of the technical data can improve aircraft maintenance technician's performance by reducing the technician's total task completion time and reducing the total number of errors made (Becker, 1990; Nugent, 1987; Thomas, 1995). The added findings from General Dynamics (1991), Masquelier (1991), and Friend and Grinstead (1992) indicate that using an HMD is more advantageous over a flat-screen display; however, errors are still made.

The primary objective of this thesis research is to determine if maintenance technicians' cannon plug pin selection and connection performance could be improved through the use of an enhanced technical data presentation method on an HMD.

Display Characteristics. Display presentation properties for graphical and scientific data have been extensively studied. Factors such as display background, item contrast, viewing distance, graphic size, graphic orientation, and amount of irrelevant information on the display have long been known to be areas of concern for graphically displayed data. When a technician is required to select and make decisions based on graphically displayed data, these items must be carefully monitored and controlled.

Pertinent information must be clearly distinguishable from its immediate background (Krendel and Wodinsky, 1960). Monochrome displays can be as reliable as color displays if the contrast, spacing, size, and density are controlled (Monk and Brown, 1975; Smith, 1963; Wagner, 1977). In fact, monochrome monitors are preferred for facilitating the display of proper images. Monochrome displays allow the best contrast between the data being presented and display background (Heleander, 1988). Display clutter is also a major hindrance to correctly locating and identifying data. If information is not essential to the situation, it must be eliminated (Gordon, 1968; Heleander, 1988; Yonas and Pittenger, 1973).

This thesis utilized the Kopin™ HMD which has a monochrome display. The data presented in the study was limited to only the exact information needed to perform the tasks requested in the test program. The Kopin™ HMD also had an adjustable eyepiece that allowed the wearer to adjust it for optimal viewing distance, thereby eliminating the visual acuity problems associated with viewing displays at improper distances (Giese, 1946; Quill, Kancler, & Batchelor, 1996).

From ensuring the basics of proper data display, investigation focus switched to ways to improve the displayed data. This thesis was concerned with enhancing the data that was presented to improve maintenance technician performance. The test program utilized in this research presented data in the form of text and graphics.

Previous studies have looked at textual information and how it is presented. Textual data should be in both upper and lower case letters for quicker and more accurate identification (Heleander, 1988). Studies by Bennett & Flach (1992), Boles & Wickens (1987), and Payne & Lang (1995) have shown that mixed-format displays, graphics and text combined, produce better performance results than either of the two alone. This finding is significant as most military technical data routinely provides either text or graphics. The graphics that usually accompany the textual data are unreadable. It is either blurry, shrunk too small to read, or vague as to what is being shown.

Wickens, Merwin, and Lin (1994) conducted a study on graphical representation of data. Their study indicated that 2-D graphics with 'visual cues' provided the best performance results from their test subjects. The visual cues provided were different colors, bold letters, highlights, and shading. Naval engineers were tested in a study by Raaijmakers and Verduyn (1996) which gave them unfamiliar fault problems and a simple help system that included graphics with visual cues. Engineer performance in detecting and identifying the faults increased when they used the help system.

A computer screen format handbook by Galitz (1985) provides an additional tip in improving the readability of data displayed on computer screens. The handbook states:

> Specific areas of the screen should be reserved for certain kinds of information, such as commands, error messages, and input fields, and maintain these areas consistently on all screens. (Galitz, 1985)

The handbook also recommends that if a program continually displays screens with similar information, not mentioned above, then the information should also be presented in the same location each time it is displayed. Consistently displaying information in the same location enables the viewer to identify data more quickly.

This thesis incorporated the recommendations and findings of the afore mentioned references. A monochrome HMD with an adjustable eyepiece was used to display textual and graphical information. The presented text was in both upper and lower case letters. Only the information required to perform the assigned task was presented. Additionally, all screens that presented the same or similar information did so in the same location on the display.

Summary

Head mounted display studies have shown improved maintenance technician performance over traditional flat-screen display methods. With careful consideration as to what data is displayed and how the data is displayed, displays can be arranged to enhance viewer performance. HMDs do inherently contain some disadvantages when used in a dynamic environment, such as in flight in an aircraft cockpit. In more static environments, such as in maintenance settings, the disadvantages of HMDs can be controlled and the advantages gained provide better technician performance. Chapter Three outlines the research methodology used in this study.

III. Methodology

Research Design Background

This research investigated the relationship between avionics maintenance technician performance and the methods used to display the technical information. The information used was presented on a single display type, a monocular head-mounted display (HMD), but varied in its containment of enhancements to the data presentation (enhancements verses no enhancements). Research conducted by Nugent (1987) indicates that the electronic, computer-based, presentation of technical data improves maintenance technician performance over the traditional paper (technical manuals) data presentation methods. Friend and Grinstead (1992) conducted research that indicates information presented on a head-mounted display improves technician performance over computer-based, flat screen laptop computers. This research investigated whether data presented on an HMD can be enhanced to improve technician performance even more. More specifically, the present study investigated the effects of graphical enhancements of relatively simple and complex equipment setups on maintenance technician performance.

Experiment Test Subjects

Avionics maintenance technicians from the 2d Bomb Wing at Barksdale AFB, LA were the test subjects in this experiment. The technicians were volunteers that were randomly chosen from the pool of available personnel at the base. Criteria for consideration in the available pool were based on time in service, time on the flightline/bench, current duties, and eyesight. Technicians had to have a minimum of four years continuous active duty experience, must have been working on the flightline/bench for at least two years, and must currently be performing maintenance duties on the flightline/bench. Technicians also had to possess at least 20/20 corrected vision and could not wear bifocals or trifocals in order to be considered in the available pool of technicians for this study.

The technician experience requirements were designed to eliminate the experience variable from entering into the analysis. Masquelier (1991) and Friend and Grinstead (1992) both showed that technician experience levels have a significant effect on technician performance. The test subjects were screened for a minimum common experience level to eliminate varying experience levels as an experiment variable. This minimum common experience level included time in service, time on station, continuous time on the flightline or test bench, and current duties.

Technician eyesight was also screened. The HMD does present problems for people who wear bifocals or trifocals, so they were eliminated from the available pool of technicians. Eyesight corrected to 20/20 was also used as a minimum baseline. Technician vision was not tested for, but technicians were asked if they had corrected 20/20 vision. Perfect eyesight is not required for HMD use, but eliminating people with eyesight problems also eliminated one potentially confounding variable.

Ocular dominance, or the dominant sighting eye, of the technician was not tested, nor is it required that the HMD be used on the dominant eye. Experiments indicate that while performing static maintenance tasks, those tasks that don't require technicians to move around -- like bench testing, technician performance is not affected by which eye views the HMD (Quill et. al., 1996). The study results do suggest that switching the HMD from eye to eye during task performance does affect overall technician task time performance. Because of this, technicians performing this experiment were discouraged from switching the HMD from eye to eye in the middle of a task.

Experiment Hardware and Software

There were several pieces of equipment used in this research. The HMD was a commercially available monocular display attached to a headband and is made by Kopin™. A 486, Pentium™ controlled portable laptop computer was used by the test administrator as the CPU, memory, and control device. The test apparatus were five multi-pin cannon plug/breakout box assemblies. The four assemblies used for the experiment were circular. The fifth assembly, which was used for practice, orientation, and training, was rectangular.

The software used in the experiment was a locally developed test program developed using Visual Basic™ 4.0 language. The technicians were presented a menu-driven test program that provided visual cues to follow. The test administrator stepped through the program using a laptop computer as the technician indicated he or she was ready to continue.

Experiment Design

Identifying the proper experiment design involved two basic steps. The first was defining what was to be measured and the second was identifying the factors -- identifying characteristics that differentiate the treatments from one another used in designing the experiment (Montgomery, 1976). From these, the research methodology was developed. This study focused on two measures: task completion time and error rate. Additionally, each technician's opinions and perceptions were collected through a post-test questionnaire and interview to supplement the quantitative analysis. Sample questions are included in Appendices A and B. The factors for this research were the number of pins on the cannon plug and data display presentation method.

There were four different circular cannon plugs used in this research, each had a different number of "female" or recessed pins: 12, 13, 55, and 79. Female cannon plugs were exclusively chosen to reduce task variance, and because the indexing and visual references are more consistently marked and readable. The cannon plugs were divided into two groups: many pins and few pins. The cannon plugs with 12 and 13 pins were in the 'few' pins group and the cannon plugs with 55 and 79 pins were in the 'many' pins group. The wide variance in pin numbers was selected to test the effect of the increased number of cannon plug pins on the maintenance technician error rate. Figure 5 shows drawings of the front view of the few pin cannon plug layouts and Figure 6 shows drawings of the front view of the many pin cannon plug layouts.

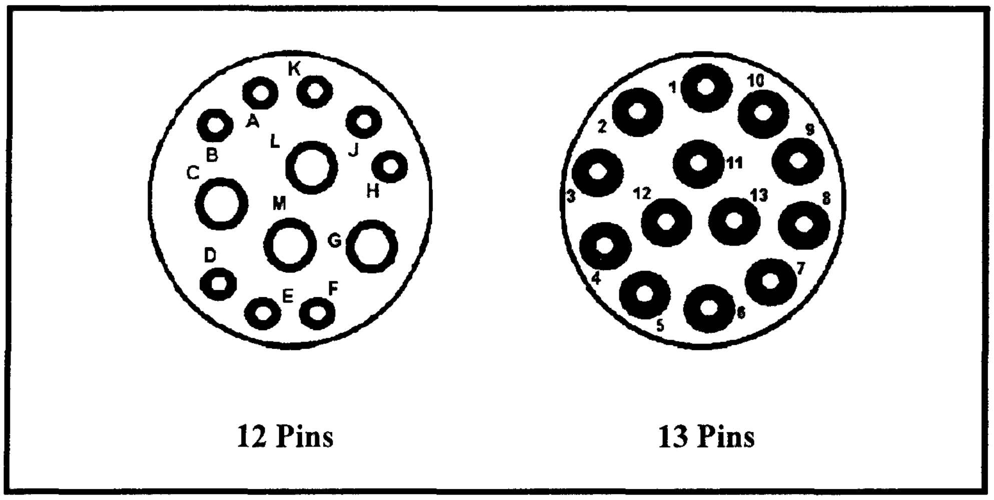


Figure 5: Graphics of Cannon Plug Faces with
'Few' Pins Used in this Research

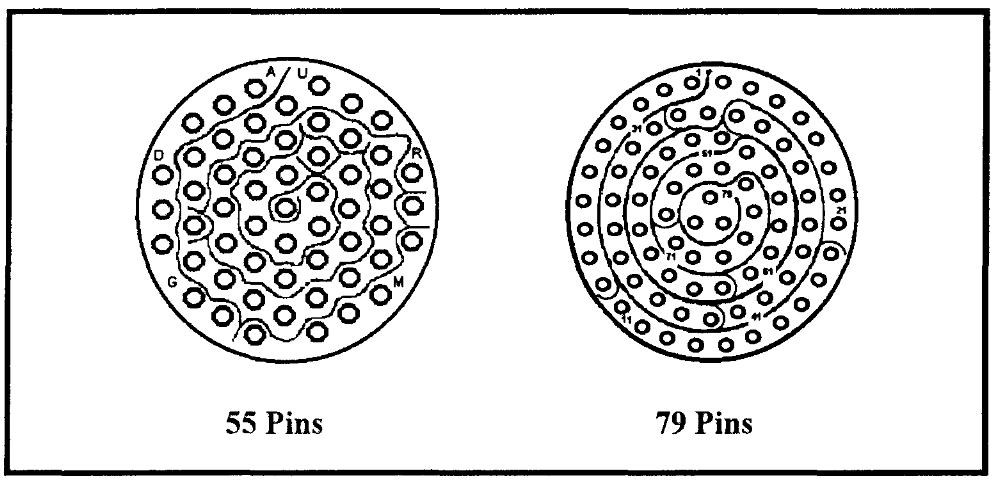


Figure 6: Graphics of Cannon Plug Faces with
'Many' Pins Used in this Research

The cannon plugs were visually referenced either alphabetically or numerically. There was one numerically indexed and one alphabetically indexed cannon plug in each of the groups. The indexing scheme of the cannon plugs was not being tested. The different indexing types were selected to be a representative sample of what technicians encounter in the field.

This experiment used four different pin combinations for each cannon plug. A random number generator was used to select the first pin combination for each cannon plug. The remaining three combinations were selected based on inter-pin distance and relative location on the cannon plug. This pin selection scheme was done to keep the pin selection and connection tasks equivalent for each of the four trials for each cannon plug. Keeping the tasks equivalent eliminated task difference as a possible source of control error in the experiment. Table 1 shows what connector type and pins were used for each of the sixteen test conditions.

Table 1: Task Condition Identification

Task Conditions		Connector Type	Pins to Connect	
Enhanced	Unenhanced	(# of Pins)	First	Second
E9a	U9a	79	24	46
E5a	U5a	55	N	s
E3a	U3a	13	9	10
E2a	U2a	12	A	F
E9b	U9b	79	15	59
E5b	U5b	55	F	x
E3b	U3b	13	4	12
E2b	U2b	12	D	J
E9c	U9c	79	6	54
E5c	U5c	55	C	v
E3c	U3c	13	2	11
E2c	U2c	12	E	K
E9d	U9d	79	47	67
E5d	U5d	55	S	h
E3d	U3d	13	5	6
E2d	U2d	12	D	H

Note: These cannon plugs are circular. The cannon plugs differ by the number of connector pins they have and their pin layout.

The technical data presentation method was either enhanced or unenhanced. Both presentations contained the same basic information that is presented in typical technical manuals: a basic picture of the cannon plug in question, index references, and a table of which cannon plug pins to connect. The enhanced presentation contained additional visual cues that highlighted or emphasized which pins to connect, which were not provided in the unenhanced presentation. Figure 7 contains examples of both presentation methods for the 55 pin cannon plug. Appendix C contains drawings of the HMD presented data for all test conditions.

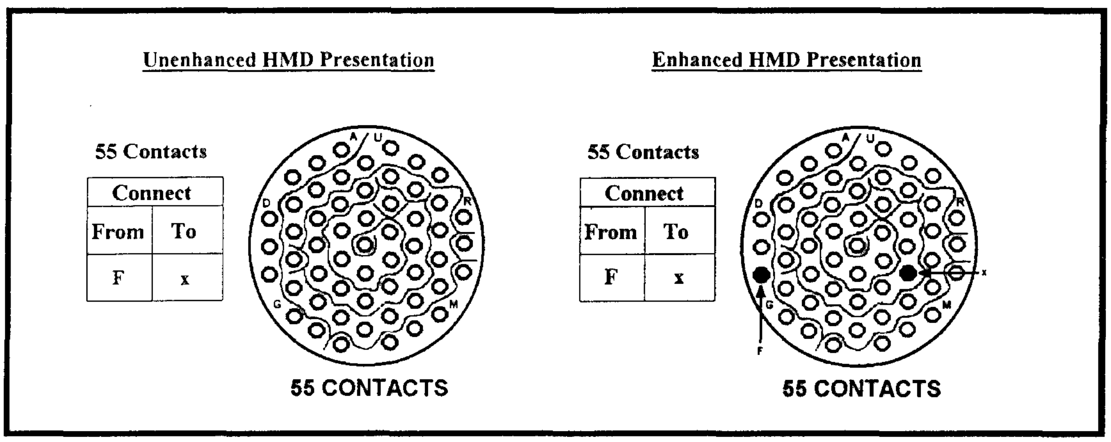


Figure 7: Enhanced and Unenhanced HMD Presentation Methods

The research methodology used was a within-subject mixed two-variable/factor randomized block design (Keppel & Zedeck, 1989). The within-subject factor was the HMD presentation method, enhanced verses unenhanced. All technicians received both the enhanced and unenhanced presentations of the four cannon plugs, twice. This design resulted in each technician performing 16 trials in each treatment or task. Sixteen tasks per technician were chosen to improve the power of the analysis of the experiment results. A minimum of eight tasks were required so that each technician would receive all of the experimental conditions. Task numbers were increased by eight in order to present all the experimental conditions for data comparison analysis. Learning effect was minimized when doubling the tasks because of the randomized block presentation order (Keppel & Zedeck, 1989).

The presentation order was obtained through a randomized block manner. Block randomization was done to avoid data presentation order effects. It was selected over other data display methods as it still provided presentation order control, without requiring counterbalancing, and allowed more generalizable results (Keppel & Zedeck, 1989). This placed no limits on the minimum number of test subjects required for a significant statistical analysis. The block randomization was accomplished as follows:

(1) The 16 tasks to be performed by each technician were divided into groups of eight, containing two of each cannon plug type with one of each of the presentation methods, enhanced and unenhanced.

(2) Each group of eight tasks was then divided in half. Each half contained one of each of the four cannon plug types of either presentation method.

(3) Tasks were then randomly assigned according to rules one and two above.

Table 13 in Appendix D shows the task order for the 28 test subjects. A Grecko-Latin square design was initially utilized; but a pilot study revealed that it appeared to have an order affect present, so it was replaced with the block randomized design. A second pilot study run using the block randomized design showed no hint of an order affect present.

Experiment Procedure

Technicians initially completed a personal background form to ensure that they met the requirements to be included in the test sample. An example of the personal background form is provided in Appendix E. The technician then completed a Human Use Research Committee (HURC) form. This form explains the technician's rights and the test administrator's responsibilities to the technician during the test. An example of the form is provided in Appendix F.

Technicians then received an initial briefing on what they would do during the experiment and initial training on the use of the HMD. The technicians completed a practice session using a rectangular cannon plug. During the practice session, technicians were exposed to the exact procedures used during the experiment.

Before starting any of the tasks, the technicians were allowed to orient themselves on the task to be performed (cannon plug pin layout and which test adapters to use). This was done to provide a common starting point for the tasks. The technicians were reminded that this evaluation was concerned with their task performance and not the actual operation of the HMD. If a technician was experiencing difficulty in operating the HMD or any of its components, the experimenter helped the technician in the proper equipment operation prior to beginning a task. If the HMD or any of its related components failed during the test, or the technician had to stop the test for any reason, that test was aborted and the technician's data was eliminated from the analysis.

For the experiment, each technician performed sixteen measured circular cannon plug pin selection/connection tasks wearing the HMD. Eight of the tasks were completed using the graphically enhanced presentation and eight were completed using the unenhanced presentation. Technicians were allowed only one selection/connection attempt per task. The error rate was calculated based on the technician's ability to correctly identify the proper pins the first time. To control for data collection variance, the same experimenter conducted all the data collection activities.

The tasks were simple by design: the technicians inserted test adapter connectors in two specific cannon plug pins. The presentation on the HMD specified which connector to use and which pins to connect. The test administrator observed the technician as the tasks were performed and recorded any observations on an experimenter observation form. An example of the form is provided in Appendix F. After the technician completed each task, the test administrator checked to see if it was completed correctly and also recorded the results on the experimenter observation form.

The task time was automatically recorded in the test program as the task was started and stopped by the experimenter at the direction of the technician. The test administrator controlled the test program advancement through the use of a portable laptop computer. The HMD worn by the technician was tethered to the laptop computer. It presented the program data and visual cues for the technician to tell the test administrator to continue the program, this allowed the technician to concentrate on the cannon plug pin selection and connection tasks. The experiment was designed to test technician cannon plug pin selection performance using an HMD, not how to operate a computer. Working as quickly and as accurately as possible was emphasized to all the technicians, but there was no time limit placed on the task completion time. The skill level required to accomplish the tasks was such that time limits were not needed and would unnecessarily complicate the analysis of the test data.

Experimenter control was achieved through standard procedures for briefing, training, interviewing, and debriefing. Examples of the scripted presentations are in Appendices B, H, I, and J. All test subjects received the same instructions and guidance.

The collected data was analyzed using a repeated measure analysis of variance (ANOVA) procedure on SPSS™ 7.5 for Windows™. The data was investigated to see if there was a statistically significant difference between the unenhanced and enhanced graphical display methods on technician task completion time and error rate. Appendix K contains the raw test data that was collected for this study. Chapter Four contains the data results and analysis of the collected test data.

Experiment Hypotheses

The overall research hypothesis was that graphically enhanced data presentations would improve technician cannon plug pin selection and connection task performance. The following hypotheses detail how technician performance was defined:

1. Fewer cannon plug pin connection errors are made using the graphically enhanced presentation on the HMD than the unenhanced presentation.

2. Pin selection/connection takes less time using the graphically enhanced presentation method than the unenhanced presentation.

3. Cannon plugs with fewer pins will have fewer connection errors than cannon plugs with many pins.

4. Cannon plugs with fewer pins will take less time to complete the task than cannon plugs with many pins.

5. For enhanced presentations, there is no statistically significant difference in time to complete the tasks between cannon plugs with many and few pins.

6. For unenhanced presentations, cannon plugs with few pins will take less time to complete the tasks than cannon plugs with many pins.

7. For enhanced presentations, there is no statistically significant difference in the number of task completion errors between cannon plugs with many and few pins.

8. For unenhanced presentations, cannon plugs with few pins will have less errors in task completion than cannon plugs with many pins.

Experiment Controls

The experimental plan, contained in Appendix C, was developed for the experimenter to follow during the data collection. The plan was used to standardize the briefing, training, and task performance instructions presented for all the technicians. This kept the variations from these areas to a minimum. This evaluation was concerned with cannon plug pin selection/connection error rates and task completion times and not the actual operation of the HMD. Additionally, the following previously mentioned actions were performed to control for experiment variation:

1. **Personnel.** Test subjects were randomly selected from the avaliable pool of avionics technicians at the 2d Bomb Wing at Barksdale AFB, LA. The technicians had a minimum of four years active duty Air Force time in service, two years flightline/bench experience, and their current jobs were on the flightline/bench. The technicians also had at least 20/20 corrected vision and did not wear bifocals or trifocals.

2. **Equipment**. If the HMD or any of its related components failed during the test, or the technician had to stop the test for any reason that test was aborted and the technician's data was eliminated from the analysis. If a technician experienced difficulty in operating the HMD or any of its components the experimenter helped the technician in the proper equipment operation prior to beginning the task.

3. **Procedures**. The same experimenter conducted all the data collection activities. The task performance time was computed by the computer program itself. The test subjects were allowed to orient themselves on the task to be performed before beginning the test (cannon plug pin layout and which test adapters to use). Technicians were allowed only one selection/connection attempt per task. There was no set time limit for task completion.

Summary

This chapter outlined the research methodology and experiment controls used to conduct this experiment. The experimental design, to include the tasks performed, experiment factors, and experiment measures used, was discussed. The experiment factors were the number of pins on the cannon plug (few verses many) and the display presentation method (enhanced verses unenhanced). The experiment measures were task completion time and technician error rate in selecting the proper cannon plug pins.

IV. Results and Analysis

Overview

Twenty-eight aircraft avionics maintenance technicians stationed at Barksdale AFB, LA each performed 16 cannon plug pin selection and connection tasks for this study. Quantitative and qualitative data were collected from all of the participating test subjects. The quantitative data are analyzed and discussed in this chapter. The qualitative data that were collected for all of the 28 participating technicians through the user evaluation questionnaire and the structured interview pertain only the usability of the HMD system and are discussed in Chapter 5.

Four of the technician's quantitative data sets were excluded from analysis. One was discarded because the testing procedure was compromised while the technician was performing the experimental tasks. The technician was given the wrong cannon plug during two of the tasks resulting in erroneous task completion time data being recorded. The quantitative data was determined unusable because of the procedural error.

A second technician's data was eliminated because the test program sequencing was improperly programmed and the wrong graphical presentations were presented to the technician during the test. The technician performed the tasks properly, but the wrong presentation resulted in the experimental design being compromised.

The other two data sets were discarded because both of the technicians indicated during the structured interview that they did not see the enhancements on the HMD presented graphics. It was verified that they did not see the enhancements by showing the technicians pictures of the enhanced graphical presentations. Consequently, because they did not see the enhanced presentations, they did not use them. Thus, the data collected for the enhanced test conditions is not valid and could not be used for analysis.

The quantitative data analysis was performed on the remaining 24 sets of data, each with 16 tasks. Eight of the tasks were completed using the unenhanced graphical presentation method and the other eight were performed using the enhanced graphical presentation method. Task completion time and task error rate were collected during the study. This resulted in 384 data points being analyzed for both task completion time and task error rate -- 192 unenhanced data sets and 192 enhanced data sets.

The quantitative data were analyzed using a repeated measure analysis of variance (ANOVA) procedure. The following sections provide the collected raw test data for the mean task completion time and task error rates. Additionally, the results from the tests of the ANOVA analysis of the eight proposed research hypotheses and the interaction between the overall average task completion time and overall error rate and the unenhanced and enhanced graphical presentation methods follow the raw data.

Research Data

This section details the raw quantitative research data collected during the course of this thesis effort. The mean task completion times are presented first, followed by the raw error data.

Task Completion Time. Table 2 and Figure 8 present the mean task completion time data for the 24 qualified test subjects. The data is presented for the 'few' pin cannon plug group, 'many' pin cannon plug group, and all the cannon plugs combined. The raw data seems to show a difference in the task completion times between the unenhanced and enhanced graphical presentation methods and cannon plug pin groups. However, the variance of the data groups is quite large. These high variances prevent any conclusions being drawn from the raw data alone. ANOVA techniques are applied later in this chapter to further test the collected data against the eight proposed research hypotheses.

Table 2: Mean Task Completion Times

Cannon Plug Connector Group	# of Data Points	Time (sec) Mean	Time (sec) Std. Dev.
Few Pins (12 & 13):	192	12.23	4.98
Unenhanced:	96	13.25	5.43
Enhanced:	96	11.21	4.27
Many Pins (55 & 79):	192	31.31	21.12
Unenhanced:	96	39.54	23.38
Enhanced:	96	23.07	14.59
All 4 Cannon Plugs:	384	21.77	18.06
Unenhanced:	192	26.40	21.46
Enhanced:	192	17.14	12.26

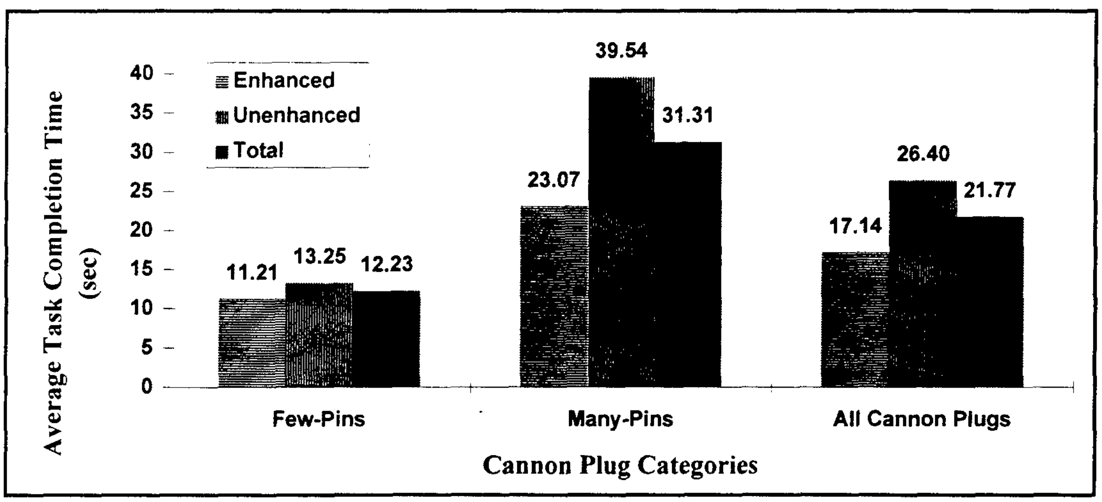


Figure 8: Mean Task Completion Times Across the Various Cannon Plug Categori0es

Task Error Rate. Table 3 and Figure 9 present the task error rate data for the 24 qualified test subjects. The data is presented for the 'few' pin cannon plug group, 'many' pin cannon plug group, and all the cannon plugs combined. The raw data seems to indicate a difference in the task error rates between the unenhanced and enhanced graphical presentation methods and cannon plug pin groups. ANOVA techniques are applied later in this chapter to further test against the eight proposed research hypotheses.

Table 3: Task Error Rates

Cannon Plug Connector Group	# of Data Points	# of Errors	Error Rate (%)
Few Pins (12 & 13):	192	17	8.85
Unenhanced:	96	12	12.50
Enhanced:	96	5	5.21
Many Pins (55 & 79):	192	52	27.08
Unenhanced:	96	43	44.79
Enhanced:	96	9	9.38
All 4 Cannon Plugs:	384	69	17.97
Unenhanced:	192	55	28.65
Enhanced:	192	14	7.29

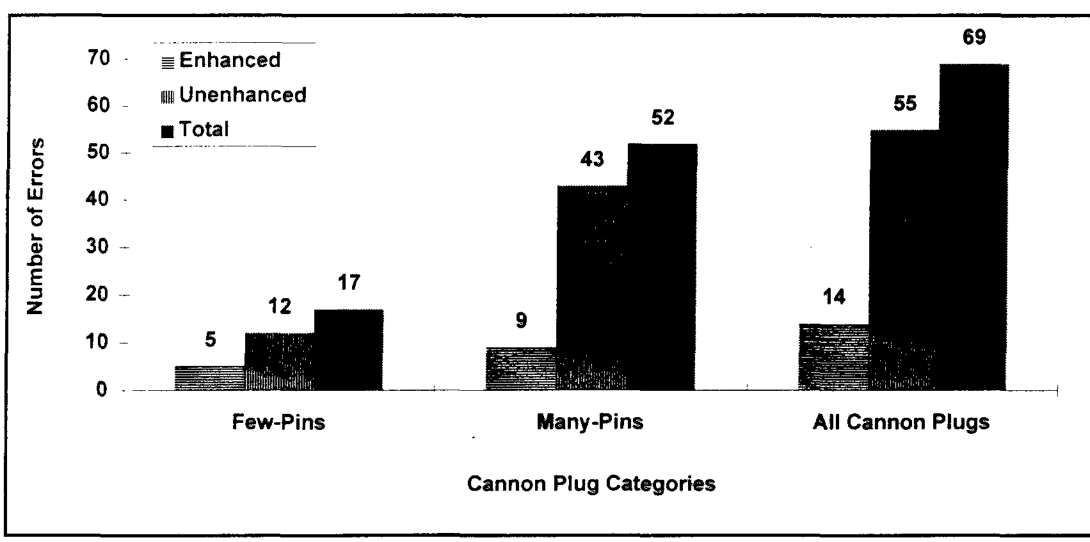


Figure 9: Task Error Rates Across the Various Cannon Plug Categories

Research Hypotheses

Hypothesis I. This hypothesis predicted that fewer cannon plug pin connection errors would be made using the graphically enhanced presentation over the unenhanced presentation. Technicians completed a total of 384 tasks -- 192 tasks using the graphically enhanced presentation and 192 using the unenhanced presentation. The raw data showed that technicians committed 14 errors when they used the enhanced presentation method to perform the tasks and 55 errors when they used the unenhanced presentation method. This result appeared to provide initial support to the hypothesis.

The results from the ANOVA analysis are shown in Table 4. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the unenhanced and enhanced presentation method error rates. A statistically significant result was observed. The F-calculated value of 20.26 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two presentation methods did not have the same error rate.

The initial data and the ANOVA analysis support the hypothesis that the enhanced presentation method would have a lower error rate than the unenhanced presentation method.

Table 4: Overall Task Error Data Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Display Type	3.190	1	3.190	**4.280**	**20.255**	0.000
Error	3.622	23	0.157			

Hypothesis II. This hypothesis predicted that the cannon plug pin selection and connection task time would be shorter using the graphically enhanced presentation over the unenhanced presentation. Technicians completed a total of 384 tasks -- 192 tasks using the graphically enhanced presentation and 192 using the unenhanced presentation. The raw data showed that technicians completed the tasks quicker using the enhanced presentation (17.14 sec) than the unenhanced presentation (26.40 sec). However, the standard deviations were so large (12.26 sec and 21.46 sec respectively) that no initial conclusions could be drawn on the validity of the hypothesis.

The results from the ANOVA analysis are shown in Table 5. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the unenhanced and enhanced presentation method mean task completion times. A statistically significant result was observed. The F-calculated value of 92.44 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two presentation methods did not have the same mean task completion times.

The analysis supports the hypothesis that the enhanced presentation method would take less time to perform the tasks than the unenhanced presentation method.

Table 5: Overall Mean Task Time Data Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Display Type	34941.586	1	34941.586	**4.280**	**92.441**	0.000
Error	8693.727	23	377.988			

***Hypothesis III*.** This hypothesis predicted that tasks performed with cannon plugs with 'few' pins (the 12 and 13 pin connectors) would have fewer errors than tasks performed with cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 384 tasks -- 192 tasks utilizing the cannon plugs with few pins and 192 utilizing the cannon plugs with many pins. The raw data showed that technicians committed 17 errors when they performed the tasks on the 'few' pin cannon plugs and 52 errors they performed the tasks on the 'many' pin cannon plugs. This result appeared to provide initial support to the hypothesis.

The results from the ANOVA analysis are shown in Table 6. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and the 'many' pin cannon plug task completion error rates. A statistically significant result was not observed. The F-calculated value of 1.21 did not exceeded the F-critical value of 4.28 and thus the null hypothesis could not be rejected.

The ANOVA analysis *counters* the hypothesis that technicians would commit fewer errors when using the cannon plugs with 'few' pins than the cannon plugs with 'many' pins. However, failing to reject the null hypothesis is not conclusive -- further research is required for better confirmation of this analysis.

Table 6: 'Few' vs. 'Many' Pin Cannon Plug Overall Task Error Data Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Few vs Many	0.128	1	0.128	**4.280**	**1.205**	0.284
Error	2.435	23	0.106			

Hypothesis IV. This hypothesis predicted that the task time of cannon plugs with 'few' pins (the 12 and 13 pin connectors) would be shorter than the task time of cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 384 tasks -- 192 tasks utilizing the cannon plugs with 'few' pins and 192 utilizing the cannon plugs with 'many' pins. The raw data showed that technicians completed the tasks more quickly on the 'few' pin cannon plugs (12.23 sec) than on the 'many' pin cannon plugs (31.31 sec). However, the standard deviations were too large (4.98 sec and 21.12 sec respectively) to allow an initial conclusion to be drawn on the accuracy of the hypothesis.

The results from the ANOVA analysis are shown in Table 7. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and 'many' pin cannon plug mean task completion times. A statistically significant result was observed. The F-calculated value of 44.79 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two cannon plug types did not have the same mean task completion times.

The analysis supports the hypothesis that tasks on the 'few' pin cannon plugs take less time to perform than the tasks on the 'many' pin cannon plugs.

Table 7: 'Few' vs. 'Many' Pin Cannon Plug Overall Mean Task Time Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-Value	P-Value
Few vs Many	8223.253	1	8223.253	**4.280**	**44.786**	0.000
Error	4223.060	23	183.611			

Hypothesis V. This hypothesis predicted that for enhanced graphical presentations only, there would be no difference between the task times of cannon plugs with 'few' pins (the 12 and 13 pin connectors) and cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 192 enhanced tasks -- 96 utilizing the cannon plugs with 'few' pins and 96 utilizing the cannon plugs with 'many' pins. The raw data showed that technicians completed the tasks more quickly on the 'few' pin cannon plugs (11.21 sec) than on the 'many' pin cannon plugs (23.07 sec). However, the standard deviations were too large (4.27 sec and 14.59 sec respectively) to allow an initial conclusion to be drawn on the credibility of the hypothesis.

The results from the ANOVA analysis are shown in Table 8. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and 'many' pin cannon plug mean enhanced task completion times. A statistically significant result was observed. The F-calculated value of 45.18 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two cannon plug types did not have the same mean enhanced task completion times.

The analysis *counters* the hypothesis that there would be no difference in the enhanced tasks on the 'few' pin cannon plugs and the 'many' pin cannon plugs.

Table 8: 'Few' vs. 'Many' Pin Cannon Plug Enhanced Presentation Method Mean Task Time Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-Value	P-Value
Enhanced	13018.547	1	13018.547	**4.280**	**45.177**	0.000
Error	6627.828	23	288.166			

Hypothesis VI. This hypothesis predicted that for unenhanced graphical presentations only, task times for cannon plugs with 'few' pins (the 12 and 13 pin connectors) would be shorter than task times for cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 192 unenhanced tasks -- 96 utilizing the cannon plugs with 'few' pins and 96 utilizing the cannon plugs with 'many' pins. The raw data showed that technicians completed the tasks more quickly on the 'few' pin cannon plugs (13.25 sec) than on the 'many' pin cannon plugs (39.54 sec). However, the standard deviations were too large (5.43 sec and 23.38 sec respectively) to allow an initial conclusion to be drawn on the reliability of the hypothesis.

The results from the ANOVA analysis are shown in Table 9. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and 'many' pin cannon plug mean unenhanced task completion times. A statistically significant result was observed. The F-calculated value of 9.29 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two cannon plug types did not have the same mean enhanced task completion times.

The analysis supports the hypothesis that the unenhanced 'few' pin cannon plug tasks would take less time to perform than the unenhanced 'many' pin cannon plug tasks.

Table 9: 'Few' vs. 'Many' Pin Cannon Plug Unenhanced Presentation Method Mean Task Time Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Unenhanced	200.083	1	200.083	**4.280**	**9.289**	0.006
Error	495.417	23	21.540			

Hypothesis VII. This hypothesis predicted that for enhanced graphical presentations only, there would be no difference between the error rates of tasks performed with cannon plugs with 'few' pins (the 12 and 13 pin connectors) and cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 192 enhanced tasks -- 96 utilizing the cannon plugs with 'few' pins and 96 utilizing the cannon plugs with 'many' pins. The raw data showed that technicians committed 5 errors when they performed the tasks on the 'few' pin cannon plugs and 9 errors they performed the tasks on the 'many' pin cannon plugs.

The results from the ANOVA analysis are shown in Table 10. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and the 'many' pin cannon plug enhanced task completion error rates. A statistically significant result was observed. The F-calculated value of 13.22 exceed the F-critical value of 4.28 and thus the null hypothesis was rejected.

The analysis *counters* the hypothesis that there would be no difference between tasks performed with cannon plugs with 'few' pins and cannon plugs with 'many' pins.

Table 10: 'Few' vs. 'Many' Pin Cannon Plug Enhanced Presentation Method Task Error Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Enhanced Error	1.505 2.62	1 23	1.505 0.114	**4.280**	**13.215**	0.001

Hypothesis VIII. This hypothesis predicted that for unenhanced graphical presentations only, tasks performed with cannon plugs with 'few' pins (the 12 and 13 pin connectors) would have fewer errors than tasks performed with cannon plugs with 'many' pins (the 55 and 79 pin connectors). Technicians completed a total of 192 unenhanced tasks -- 96 utilizing the cannon plugs with 'few' pins and 96 utilizing the cannon plugs with 'many' pins. The raw data showed that technicians committed 12 errors when they performed the tasks on the 'few' pin cannon plugs and 43 errors they performed the tasks on the 'many' pin cannon plugs.

The results from the ANOVA analysis are shown in Table 11. The overall F-test was used to test for statistical significance at the 0.05 significance level. The null hypothesis stated there was no difference between the 'few' pin cannon plug and the 'many' pin cannon plug unenhanced task completion error rates. A statistically significant result was observed. The F-calculated value of 62.69 exceeded the F-critical value of 4.28 and thus the null hypothesis was rejected. The two cannon plug types did not have the same error rate.

The initial data and the ANOVA analysis support the hypothesis that for unenhanced presentations, fewer errors would be committed on cannon plugs with 'few' pins than on cannon plugs with 'many' pins.

Table 11: 'Few' vs. 'Many' Pin Cannon Plug Unenhanced Presentation Method Task Error Analysis

Source of Variance	Sum of Squares	df	Mean Square	Critical F-Value	Calculated F-value	P-Value
Unenhanced	14.083	1	14.083	**4.280**	**62.694**	0.000
Error	5.167	23	0.225			

Summary of Results

The task completion time and error rate data collected for this thesis indicate that the enhanced graphical presentation method fosters improved technician performance over the unenhanced graphical presentation method. The compiled data supports the hypotheses that the enhanced presentations reduce technician task completion time and produce fewer technician errors. The research data seems to indicate that the enhanced presentations produced improved technician performance in every measured instance, except one.

It was hypothesized that the enhanced presentation would produce equivalent task completion times (Hypothesis V) for the 'few' and 'many' pin cannon plugs. The experiment results counter Hypothesis V and indicated that there was a difference in the task completion time between the different cannon plug types. The 'many' pin cannon plugs took longer to complete the experimental tasks than the 'few' pin cannon plugs.

It was also hypothesized that the enhanced presentation would produce equivalent error rates (Hypothesis VII) for the 'few' and 'many' pin cannon plugs. The experiment results counter Hypothesis VII and indicated that there was a difference in the error rate between the different cannon plug types. The 'many' pin cannon plugs statistically produced more errors than the 'few' pin cannon plugs.

Additionally, when the overall error data was analyzed for differences between the 'few' and 'many' pin cannon plugs (Hypothesis III), no statistically significant difference was found. These outcomes may seem to indicate that technician performance was not improved over the unenhanced presentation, but a closer examination of the data indicates otherwise. The enhanced presentation resulted in lower task completion times, fewer errors, and smaller standard deviations for both the 'few' and 'many' pin cannon plugs over the unenhanced presentation method. The enhanced presentation improved technician performance for both cannon plug types even though it did not eliminate the difference between them.

The qualitative data collected from the test participants was used primarily by Armstrong Laboratory to evaluate the HMD system that they provided for this thesis effort. The questions and replies dealt with the usability of the HMD system and are discussed in the next chapter.

V. Discussion, Conclusions, and Recommendations

Overview

This chapter contains a discussion of the results of the quantitative data collected during this research and its support for the experimental hypotheses that were proposed. The qualitative data that was collected is addressed and the important findings are highlighted. Conclusions are drawn from the results of this experiment and analysis and recommendations for further research are proposed.

Discussion of Quantitative Results

The overall mean task completion time and task error data collected for this thesis supports the hypotheses that when the technicians used the enhanced data presentation to complete the tasks they performed better. The mean task completion time analysis of the measured instances: enhanced vs. unenhanced overall, 'few' vs. 'many' pin connectors overall, and 'few' vs. 'many' pin connectors (unenhanced presentation only) indicated that the proposed hypotheses where indeed correct. The task error rate analysis of the measured instances: enhanced vs. unenhanced overall and 'few' vs. 'many' pin connectors (unenhanced presentation only) also indicated that the proposed hypotheses where indeed correct.

It was initially believed that the enhanced presentation would produce almost equal error rates and mean task times between the two cannon plug groups ('few' and 'many' pins), but the collected data indicates otherwise. The mean task completion time for the 'few' vs. 'many' pin connector was shown to be different, countering the proposed hypothesis. The analysis for this hypothesis indicated that the 'many' pin connector mean task time was longer than the 'few' pin connector. The task error rate for the 'few' vs. 'many' pin connector was also shown to be different. Fewer errors were committed when the technicians used the 'few' pin connector than the 'many' pin connector.

The data for the enhanced presentation method may seem to indicate that technician performance was not improved over the unenhanced presentation, but a closer examination of the data indicates otherwise. The enhanced presentation resulted in lower task completion times, fewer errors, and smaller standard deviations for both the 'few' and 'many' pin cannon plugs over the unenhanced presentation method. The enhanced presentation improved technician performance for both cannon plug types even though it did not eliminate the difference between them.

The overall results of this research indicate that using enhanced graphical presentation methods on an HMD produced better technician performance, as measured in mean task completion time and error rate. A closer analysis of the collected data does raise a few unanswered concerns that were not addressed in the initial experimental design. These concerns are detailed below.

Cannon Plug Design. Besides the indexing scheme, the cannon plugs were also different physical sizes, physically arranged differently (see Figures 5 and 6), used different size connector pins, had different indexing number colors, and had different color cannon plug faces. These variables were not controlled for, nor were they considered important in the experimental design. Because of the appearance of the cannon plug layout and learning effect discussed later in this chapter, these variables may need to be reinvestigated.

Cannon Plug Layout. The cannon plugs used in this thesis had both alphabetical and numerical indexing schemes. The cannon plugs also were indexed in a variety of different ways. These variables were not considered important enough to control for in the experimental design. Looking at the raw data, as shown in Table 12, these variables appear to produce some varying results. It appears that the indexing scheme produces different results between the 'few' pin connector (12 and 13) and the 'many' pin connector (55 and 79) groups.

Table 12: Raw Cannon Plug Type Data

Cannon Plug Type	Indexing Scheme	Mean Task Time (sec)	Error Rate
12 Pin	Alphabetical	13.32	3
13 Pin	Numerical	11.14	14
55 Pin	Alphabetical	30.67	35
79 Pin	Numerical	31.95	17

It could be that the indexing scheme, marking style, character size, color, or type on each of the cannon plugs produces different results. The alphabetical indexing may be more difficult to read on the 12 pin cannon plug than the numerical indexing on the 13 pin cannon plug; but, as seen in the collected data, produces less errors. As witnessed in the quicker task completion time and higher error rate, the indexing on the 55 pin cannon plug may be easy to read, but more obscure than the 79 pin cannon plug. Because the experimental design was not set up to test this relationship, it can only be said that the appearance of an effect exists and is discussed later in the recommendations section of this chapter.

Learning Effect. The randomized block design of the HMD graphical presentation order was used to minimize the learning effect from occurring. As shown in Table 13, it appears that the learning effect does indeed occur. The data is arranged in groups of four trials. The 16 trials each technician performed were divided into blocks of four trials and tallied across all 24 applicable data sets. It appears that the randomized block design of the HMD graphical presentation order did produce a small order effect. The second set of eight trials appears to have a lower mean task time and error rate.

Table 13: Raw Trial Group Data

Data Group	Mean Task Time (sec)	Error Rate
Trials 1-4	24.51	20
Trials 5-8	24.82	18
Trials 9-12	19.25	15
Trials 13-16	18.47	16

It appears that technicians experienced the learning effect after performing the first set of eight trials. It is likely that after seeing all eight presentation types in the first eight trials, the technicians learned the presentation scheme. It could also be that the training session was not long enough and technicians simply took a while to learn the HMD setup and display information. Once again, because the experimental design was not set up to test this relationship, it can only be said that the appearance of an effect exists.

Discussion of Qualitative Results

Data, in the form of a questionnaire and interview, were collected from all 28 of the test participants. Most of the data was directed at the usability and comfort of use of the HMD. This data was used by Armstrong Laboratory in a separate study involving different wearable computer systems. The data that did pertain to this study is chronicled below.

Information Presented on the HMD. The technicians were asked if the information presented on the HMD was readable and if and when they noticed a difference in presentation types (unenhanced vs. enhanced). All 28 technicians indicated that the information itself was mostly legible. Some references, such as numbers and the extreme corners of the HMD were said to be fuzzy; but, all indicated that the HMD was adequate in presenting the data.

Another comment of importance to note was that some technicians were apprehensive about relying on the enhanced presentations. The reasons given for not wanting to use the enhancements were that they did not trust the presentation, the plugs were easy to read, and they felt more comfortable counting the pins out. The technicians indicated that the pin counting and mistrust of presentation were the result of encountering numerous technical orders that were improperly marked and that they did not trust technical data.

HMD Use. The technicians in this study only wore the HMD system for about a half an hour. The tasks that they performed were in a static environment with few outside distracters or interferences. Even with this limited experience, the technicians provided insightful comments about the HMD and its possible uses.

Technicians were asked about the HMD and their ability to use it in their present jobs. The HMD setup used in this research posed many concerns to the technicians. The major concerns were the eye strain brought on by switching between the cannon plug and HMD, the extra clips and accessories that interfered with the HMD use (there was an earpiece and microphone that were not used), and the weight of the system causing headaches and sweating that would cause the HMD to slip down on the forehead.

However, the technicians overwhelmingly indicated that the HMD would be an asset to them in the performance of their daily duties. Twenty-three of the technicians said the HMD could be used in troubleshooting, schematic tracing, or tasks that required their hands to be free. Other suggested uses were in dark, tight places, during nighttime operations, and on tasks that required two people to perform. The suggestion was that technicians could be electronically connected to the same reference and could work together better by using the HMD.

Technician Suggestions. The technicians were asked if they could think of any tasks they perform or maintenance scenarios in which an HMD setup might be useful. Many suggestions were provided and many were extremely perceptive. The most mentioned advantage would be from putting Technical Orders (TOs) on the HMD.

Technicians felt that having wiring diagrams, schematics, and check lists on an HMD would enable technicians to concentrate on the task and not the data needed to perform the task. As one technician put it, some tasks require one hand to hold a flashlight, one hand to hold the test leads, one hand to hold the screwdriver, one hand to operate the test equipment, and one hand to turn the page in the TO -- "even an octopus would be hard pressed" to do the task properly.

Other suggestions included hooking the HMD up to an on-line system that would enable the wearer to access any and all the information needed to do their job. Suggested information included supply information, core automated maintenance system data, all the aircraft maintenance history, the world-wide web, and e-mail. Incorporating the HMD into a complete system of miner's light, ear defenders, radio, and, inter-phone was also frequently mentioned.

Conclusions

The results of this research suggest that enhanced cannon plug pin selection task data presented on an HMD would be useful in improving maintenance technician performance. Technicians completed the cannon plug pin selection and connection tasks quicker and committed fewer errors when they used the enhanced HMD data presentation to perform the task. Analysis of the obtained data revealed statistically significant results that indicated that the enhanced data presentation method did reduce the task performance time and error rate.

Qualitative data obtained from technician feedback also suggest that HMD systems would be advantageous for and used by technicians in the performance of their maintenance duties. Technicians reported that they had very few problems using the HMD and would like to see some type of HMD system available for their use.

Recommendations for Future Research

The full portability capabilities of current HMD systems was not tested in this study. The technicians that participated in this study did not have to move around to perform the required maintenance tasks. Flightline maintenance tasks and tasks that require technicians to move around and interact with their environment should be investigated. The technicians in this study suggested system troubleshooting tasks, inspection tasks, schematic and troubleshooting chart reading tasks, and tasks that required coordinated teams of technicians operating concurrently as possible future avenues of study.

HMDs and HMD technology has greatly advanced in just the past few years. According to three articles from inquiry.com on the World Wide Web (Displays, 1996; Little Displays, 1996; Motorola, 1995), newer systems are incorporated into regular eyeglass frames, offer look-through capability, and are completely portable. These systems could eliminate the problems of the current HMD system cited by the technicians used in this study. Investigation of such HMD systems to see if they could be used in a maintenance environment may result in improved technician performance.

The impetus for this study, cannon plug pin selection and connection errors, is still not completely addressed in this thesis. Future studies should investigate various ways to further reduce technician errors. Other HMD types and improvements to cannon plug design, such as pin layout, number of pins, pin layout style, color and numbering schemes, and pin indexing (alphabetical vs. numerical) should be studied to see if they could improve technician performance. Additionally, a more rigorous examination in graphical enhancements should be performed.

Technicians should be thoroughly familiar with the graphical enhancements and how to use them. The technicians should then be instructed to trust and use the enhancements. Identifying the enhancements and forcing the technicians to use them would eliminate the uncertainty of whether or not the technicians actually noticed the enhancements and if they actually used them, as seen in this study. Identifying improved methods to present task information and the most user friendly cannon plug design could help to improve technician performance resulting in reduced maintenance costs and increased equipment availability. For these reasons, further research in the presentation of task information and cannon plug design should be pursued.

Appendix A: User Evaluation Questionnaire

Test Subject Number: __________

Please answer the following questions based on your participation in the experiment. This questionnaire is divided into three sections, with questions on visual aspects related to the use of the HMD display, questions on the information presented on the HMD, and general questions on the HMD usability. Please read the questions carefully and put a check mark in the appropriate block. The scale for the first two sections is as follows:

Very Satisfactory **Very Unsatisfactory**

A B C D E

I. Questions on the visual aspects of the display:

	A	B	C	D	E
1. Capability of switching your attention from the display to your work					
2. Adequacy of the screen size for displayed information					
3. Head piece comfort					
4. Ability to focus the HMD					
5. Brightness of the HMD display					
6. Glare on the HMD screen					
7. Capability of positioning the HMD					

II. Questions on the information presented:

	A	B	C	D	E
1. Readability of all of the information on the screen					
2. Spacing of information on the display screen (lack of clutter, etc.)					
3. Cannon plug picture graphics					
4. Resolution and clarity of the graphic displays					
5. Contrast between the information displayed and the background					

Test Subject Number: __________

Please answer the following questions according to your experience with the HMD in this experiment. The scale for the this section is as follows:

Not a Problem				**Serious Problem**
A	**B**	**C**	**D**	**E**

III. General questions on the HMD use:

	A	B	C	D	E
1. Eye strain					
2. Blurring					
3. After/ghost images after discontinued use of HMD					
4. Headaches from using the HMD					

Thank you for participating in this experiment.

Appendix B: Structured Interview

Test Subject Number: _________

This interview is conducted after the test subject has completed the experiment and has filled out the User Evaluation Questionnaire, Appendix A. The interview is conducted in the same room in which the technician performed the tasks. The test administrator asks the following questions and solicits responses from the test subject. Printed copies of the HMD presented data, Appendix C, are used as references while these questions are being asked and answered.

The following questions pertain to the information presented on the display device:

1. Which type of information (text, graphics) was easier to read on the HMD? Why?

2. Were the graphics detailed enough so that you could recognize the features and index of the cannon plug being represented? How?

3. Did any of the presentation methods enable you to better identify and locate the pins that you were to connect? Which ones? How? (Use the printed screen graphics while asking this question.)

4. In your own words, describe the difference between the different presentation methods.

5. When presented with the unenhanced data, did you use the HMD or did you just use the cannon plug itself?

6. When presented with the smaller numbered cannon plugs, did you use the HMD or just the cannon plugs themselves?

Test Subject Number: __________

The following questions pertain to the HMD used during the evaluation:

1. How difficult was it to adapt to the HMD? Explain.

2. Can you describe anything you did not like about the HMD?

3. Did you have any problems with glare on the HMD? If so, how did you compensate?

4. Would this device work on the flightline? Why or why not?

5. Which maintenance tasks would be easier if technical data was presented on the HMD?

The following questions pertain to the physical aspects of using the HMD:

1. Did you have any visual problems (blurring, problems focusing, flickering, etc.) while using the HMD?

2. Did you get a headache or suffer from eye strain while using the HMD?

3. Did you have any problems with the HMD headband?

4. (If the technician wears glasses) was it difficult using the HMD while wearing glasses?

The following questions pertain to the cannon plug pin selection/connection task performed during the evaluation:

1. Can you think of any maintenance tasks in which the HMD would work?

2. Are there any physically distinguishable tasks where using the HMD would work particularly well (tasks requiring hands free or tight places)? Not work?

Appendix C: HMD Presented Data

Practice Cannon Plug

The following are pictures of the actual screens that are displayed on the HMD for the technician during the experiment. The unenhanced screens have the pin numbers to connect in the "connect from - to" table to the left of the cannon plug picture. The unenhanced presentations have the same pin pairs as the enhanced presentations.

51 Contacts

Connect	
From	**To**

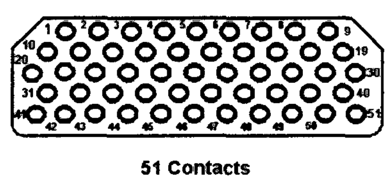


Figure 10: Practice Cannon Plug HMD Graphical Presentation

The practice tasks show the same graphical presentation for each of the four tasks. The only difference is that the pins in the "connect to from - to" table were changed for each of the four practice tasks.

12 Pin Cannon Plug

Only the basic screen is shown for the unenhanced graphical presentations. The four unenhanced graphical presentations use the same pin combinations as the enhanced graphical presentations.

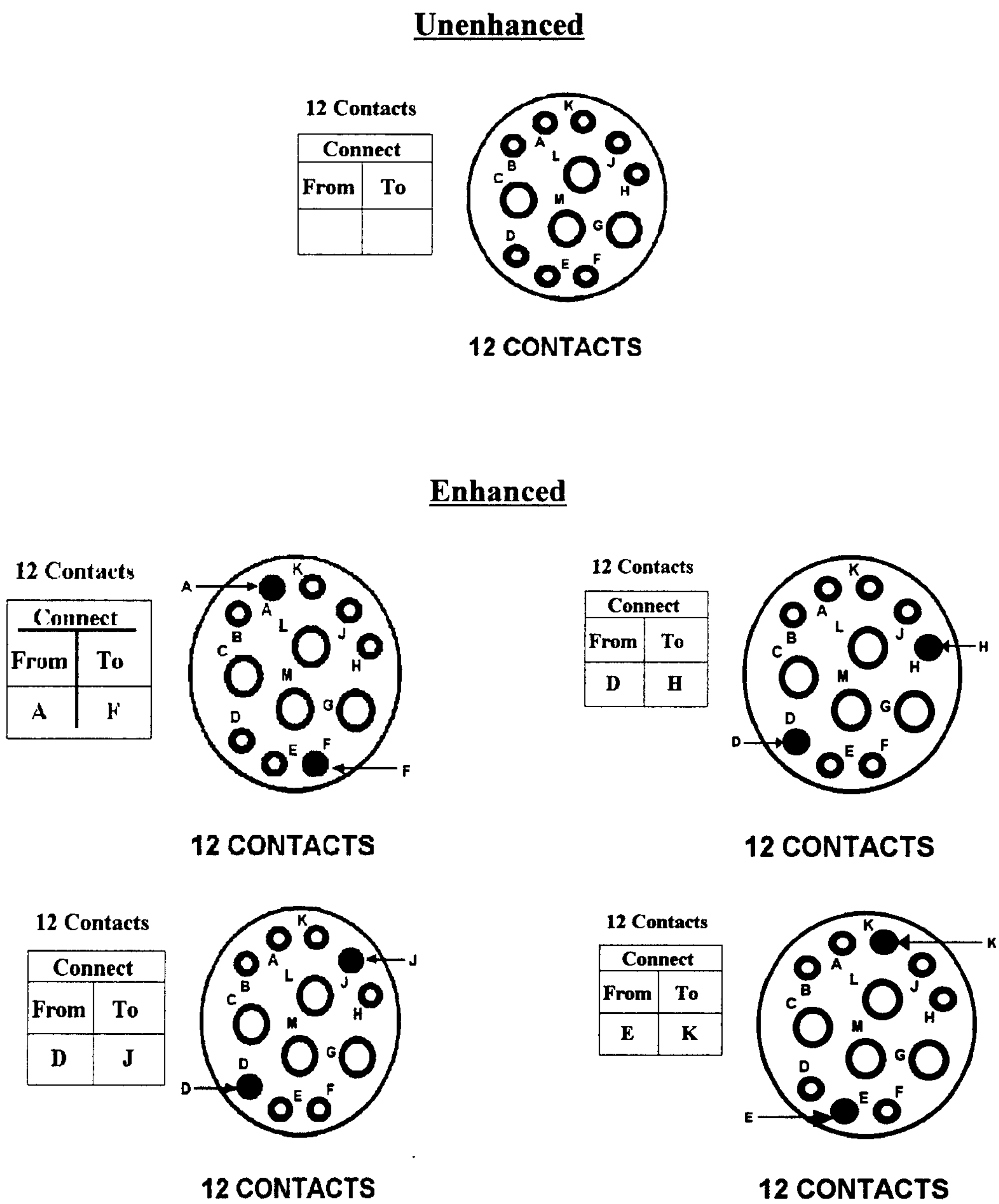
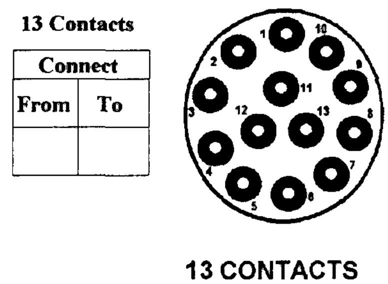


Figure 11: 12 Pin Cannon Plug HMD Graphical Presentations

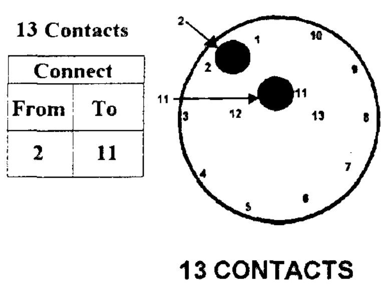
13 Pin Cannon Plug

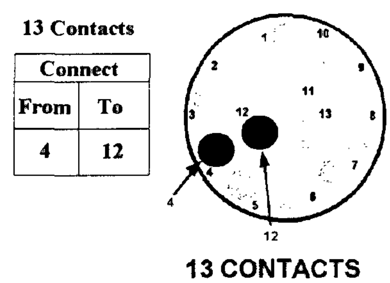
Only the basic screen is shown for the unenhanced graphical presentations. The four unenhanced graphical presentations use the same pin combinations as the enhanced graphical presentations.

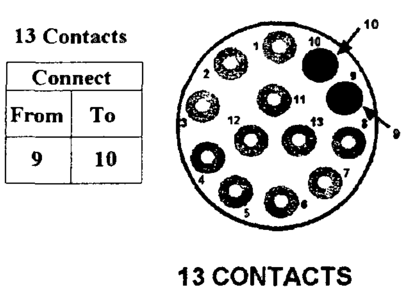
Unenhanced



Enhanced







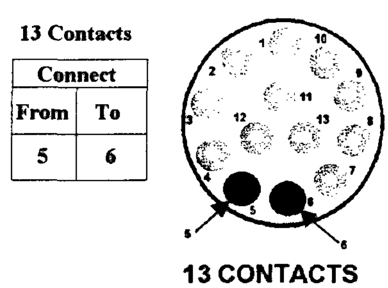


Figure 12: 13 Pin Cannon Plug HMD Graphical Presentations

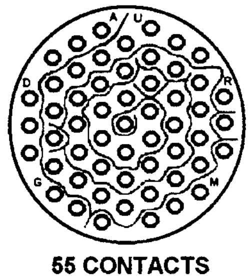
55 Pin Cannon Plug

Only the basic screen is shown for the unenhanced graphical presentations. The four unenhanced graphical presentations use the same pin combinations as the enhanced graphical presentations.

Unenhanced

55 Contacts

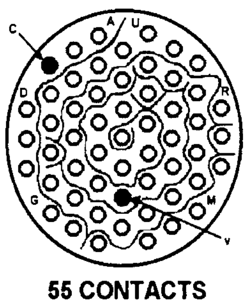
Connect	
From	To



Enhanced

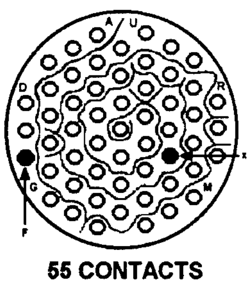
55 Contacts

Connect	
From	To
C	v



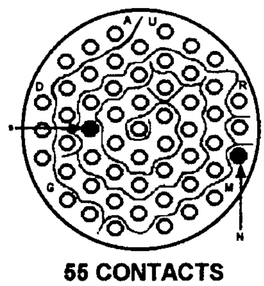
55 Contacts

Connect	
From	To
F	x



55 Contacts

Connect	
From	To
N	s



55 Contacts

Connect	
From	To
S	h

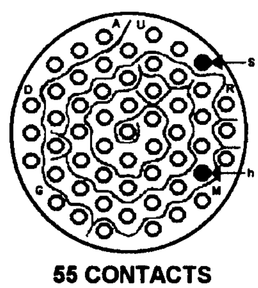


Figure 13: 55 Pin Cannon Plug HMD Graphical Presentations

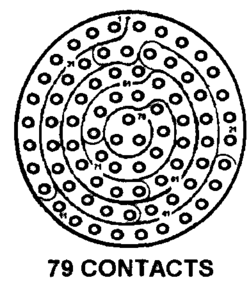
79 Pin Cannon Plug

Only the basic screen is shown for the unenhanced graphical presentations. The four unenhanced graphical presentations use the same pin combinations as the enhanced graphical presentations.

Unenhanced

79 Contacts

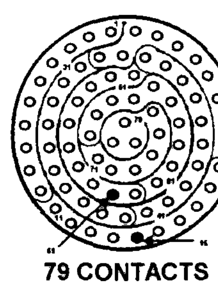
Connect	
From	To



Enhanced

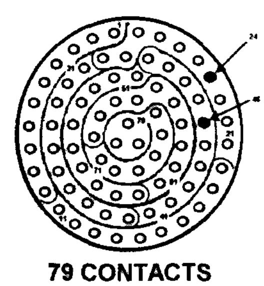
79 Contacts

Connect	
From	To
15	59



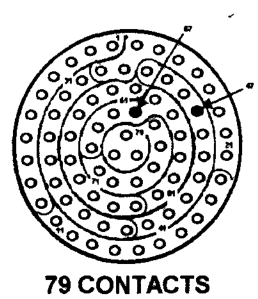
79 Contacts

Connect	
From	To
24	46



79 Contacts

Connect	
From	To
47	67



79 Contacts

Connect	
From	To
6	54

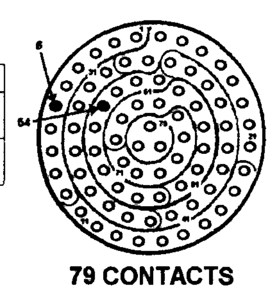


Figure 14: 79 Pin Cannon Plug HMD Graphical Presentations

Appendix D: Experimental Plan

(Adapted from Masquelier, 1991)

This appendix outlines the procedures that are used in this experiment and an overview of the experiment background. Chapter Three contains a complete description of the experiment methodology used in this research

Description of Evaluation

Purpose

The purpose of this study is to evaluate the effect that information presented on a monocular Head-Mounted Display (HMD) has on technician performance of cannon plug pin selection and connection tasks.

Subjects

Avionics maintenance technicians from the 2d Bomb Wing at Barksdale AFB, LA are test subjects in this experiment. The technicians are volunteers randomly chosen from the pool of available personnel at the base. Criteria for consideration in the available pool are based on time in service, time on the flightline/bench, current duties, and eyesight. Technicians had to have a minimum of four years continuous active duty experience, must have been working on the flightline/bench for at least two years, and must currently be performing maintenance duties on the flightline/bench. Technicians must also have at least 20/20 corrected vision and cannot wear bifocals or trifocals in order to be considered in the available pool of technicians for this study.

Hardware

There are several pieces of equipment used in this research. The HMD is a monocular display attached to a headband and is made by Kopin™. A portable laptop computer is used by the test administrator as the CPU, memory, and control device.

The test apparatus are five multi-pin cannon plug/breakout box assemblies. The four assemblies used for the experiment are circular. The fifth assembly, which is used for practice, orientation, and training, is rectangular.

Software

The software used in the experiment is a locally developed test program in Visual Basic™ 4.0 language. The technicians are presented a menu driven test program that provides visual cues to follow. The test administrator steps through the program using a laptop computer as the technician indicates he or she is ready to continue.

Experiment Tasks

Each technician performs sixteen measured cannon plug pin selection/connection tasks wearing the HMD. Eight of the tasks are completed using the graphically enhanced presentation and eight are completed using the unenhanced presentation. The tasks are simple by design: The technicians insert test adapter connectors in two specific cannon plug pins. The presentation on the HMD specifies which connector to use and which pins to connect. Table 12 shows what connector type and pins are used for each of the sixteen test conditions.

Table 14: Task Condition Identification

Task Conditions		Connector Type (# of Pins)	Pins to Connect	
Enhanced	Unenhanced		First	Second
E9a	U9a	79	24	46
E5a	U5a	55	N	s
E3a	U3a	13	9	10
E2a	U2a	12	A	F
E9b	U9b	79	15	59
E5b	U5b	55	F	x
E3b	U3b	13	4	12
E2b	U2b	12	D	J
E9c	U9c	79	6	54
E5c	U5c	55	C	v
E3c	U3c	13	2	11
E2c	U2c	12	E	K
E9d	U9d	79	47	67
E5d	U5d	55	S	h
E3d	U3d	13	5	6
E2d	U2d	12	D	H

Note: These cannon plugs are circular. The cannon plugs differ by the number of connector pins they have and their pin layout.

Conditions

Table 15 shows the test subject number and the task condition order the technician performs during each of the sixteen tasks. The 28 test subjects are shown. The design of the task conditions in Table 15 is accomplished by using block randomization. This is done to avoid data presentation order effects. Chapter Three provides further clarification on the experiment research methodology.

Table 15: Task Condition Order

Subject Number	Task Number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	E9c	E5c	U2c	E3d	E2a	U5d	U9a	U3b	U9b	U2d	U5b	E3c	E2b	U3a	E9d	E5a
2	E5c	E3c	E2d	U9a	E9c	U5b	U2a	U3d	E9d	E2b	U5d	E3b	U3a	E5a	U9b	U2c
3	U5c	E9d	U3d	E2d	E3b	U9b	U2c	E5d	U3a	E2b	U9a	U5b	E5a	E3c	U2a	E9c
4	U9b	U3c	U2b	E5c	E3b	E2c	E9c	U5d	E5b	U9d	U3d	E2d	U5a	E9a	E3a	U2a
5	U2a	E3c	U9a	E5b	E2b	U3b	U5a	E9d	U5d	E2c	E9c	U3d	U9b	E3a	U2d	E5c
6	U3c	U2b	U9b	E5c	E3a	E2a	E9a	U5b	E5d	E2d	E9d	U3d	U9c	E3b	U2c	U5a
7	E5a	E2a	E3b	E9c	U5b	U2c	U3c	U9d	E9b	U3c	E2d	E5c	U9a	U2b	U5d	E3d
8	U2b	E3a	U5a	E9d	U3d	U9a	E5b	E2d	E5d	E9b	E2a	E3b	U9c	U3c	U5c	U2c
9	E2b	E3b	E9b	U5c	U3d	U9a	E5a	U2d	U2a	E9d	E3a	U5d	U3c	U9c	E5b	E2c
10	U5a	E2a	U3b	E9d	U2c	U9a	E5b	E3a	E3c	U5c	U2d	U9b	U3d	E2b	E9c	E5d
11	E2c	E9b	U3d	U5c	U2d	E3b	U9d	E5b	E5d	U2b	E3c	E9a	U5a	U9c	U3a	E2a
12	E5c	E9b	U2d	E3d	E2b	U5a	U9d	U3b	E3a	U9a	E2a	U5b	E9c	U3c	U2c	E5d
13	U5d	U2a	E9d	E3b	E5c	U3d	E2d	U9c	U5b	E9b	E2b	U3c	E5a	E3a	U2c	U9a
14	U2b	E9b	U5c	E3c	E2a	U9d	E5d	U3a	E9c	U3d	U5a	U2d	E2c	E5b	U9a	E3b
15	U2c	U3d	U9c	U5a	E2a	E9d	E3a	E5b	E2d	E3c	E9b	E5d	U2b	U3b	U9a	U5c
16	U5c	U3c	U2c	U9b	E2a	E3a	E9a	E5b	E5d	U2b	E9d	U3d	E2d	E3b	U5a	U9c
17	U2c	U5b	E9b	U3a	E5a	E3d	U9c	E2b	E5c	U2d	U9d	U3c	E9a	U5d	E3b	E2a
18	U9c	E5a	E3b	E2a	U2c	U3a	E9a	U5b	U2b	U3d	U9b	U5c	E2d	E3c	E9d	E5d
19	E9d	U2c	U3c	E5d	E2a	U9b	E3d	U5a	U3a	E2d	U9a	U5b	U2b	E9c	E3b	E5c
20	E2a	E5d	E9d	U3d	E3a	U2b	U9c	U5a	U5b	E9b	E2d	E3c	U3b	U2c	E5c	U9a
21	E2c	E3d	U9a	U5c	E9d	U3b	U2a	E5b	E5d	E3a	U2d	U9b	U5c	E2b	E9c	U3c
22	E9b	U2b	U3c	E5b	E3a	E2c	U9d	U5a	U9c	U3b	E5c	U2a	E2d	U5d	E9a	E3d
23	U9d	E5c	E2b	E3d	U5b	U2a	E9b	U3c	U9c	U3b	U5a	U2c	E5d	E3a	E9a	E2d
24	U2d	E5a	U3a	E9d	U9c	E2c	E3c	U5c	E2a	U9a	U3b	E5d	U5b	E3d	U2b	E9b
25	E5b	E9a	U3d	U2d	U5d	U9b	E2b	E3b	U9c	U5c	U3c	E2c	E9d	E5a	U2a	E3a
26	E2b	E3d	U9d	E5c	U2d	U3a	U5a	E9c	E2c	E3c	E9b	U5d	E5b	U3b	U9a	U2a
27	U2d	E5c	U3d	E9b	E3a	U5b	E2b	U9d	E9c	U3b	E5a	U2c	U9a	E2a	U5d	E3c
28	U2a	E3a	E9d	U5c	E5a	U9c	E2c	U3d	E3c	E9a	E2d	U5d	U2b	E5b	U3b	U9b

Note: Avionics technicians completed 16 tasks each, eight graphically enhanced and eight unenhanced.

Experiment Hypotheses

1. Fewer cannon plug pin connection errors are made using the graphically enhanced presentation on the HMD than the unenhanced presentation.

2. Pin selection/connection takes less time using the graphically enhanced presentation method than the unenhanced presentation.

3. Cannon plugs with fewer pins will have fewer connection errors than cannon plugs with many pins.

4. Cannon plugs with fewer pins will take less time to complete the task than cannon plugs with many pins.

5. For enhanced presentations, there is no statistically significant difference in time to complete the tasks between cannon plugs with many and few pins.

6. For unenhanced presentations, cannon plugs with few pins will take less time to complete the tasks than cannon plugs with many pins.

7. For enhanced presentations, there is no statistically significant difference in the number of task completion errors between cannon plugs with many and few pins.

8. For unenhanced presentations, cannon plugs with few pins will have less errors in task completion than cannon plugs with many pins.

Data Collected

The total time to complete each task and the cannon plug pin selection/connection error rate is collected. Additionally, demographic data is collected using a Personal Background Form (Appendix E). During the experiment, notes and observations are documented (Appendix G). After the technician completes the experiment, the User Evaluation Questionnaire is used to ascertain the users' evaluation of the experiment (Appendix A). A structured interview is then performed to receive comments on the HMD, presentation methods, and the techniques used for pin identification (Appendix B). Determining users' likes, dislikes, and concerns is important in trying to design a system that meets the users' needs.

Controls

The following actions are performed to control for experiment variation:

1. Test subjects are avionics technicians and have a minimum of four years active duty Air Force time in service, two years flightline/bench experience, and their current job is on the flightline/bench. This provides a common experience minimum for the tests and allowed experience levels to be controlled for.

2. Given #1, test subjects are volunteers randomly selected from the available pool of avionics technicians at the 2d Bomb Wing, Barksdale AFB, LA.

3. The same experimenter conducted the data collection activities.

4. The graphical data presented in the enhanced and unenhanced tasks is the same for all test subjects. The order of presentation is counterbalanced to account for any presentation order anomalies.

5. Test subjects have at least 20/20 corrected vision and do not wear bifocals or trifocals.

6. The task performance time is computed by the computer program itself. The test administrator starts and stops the test sequence at the direction of the test subject and the program automatically computes the test duration time.

7. The test subjects are allowed to orient themselves on the task to be performed before beginning the test (cannon plug pin layout and which test adapters to use). This is done to provide a common starting point for the tasks.

Experiment Procedures

Task Assignment

Avionics technicians act as test subjects. The technicians are volunteers randomly chosen from the available pool and assigned one of the subject numbers outlined in Table 15. Each technician performs 16 cannon plug pin selection/connection tasks. Eight of those tasks are done using the HMD and an enhanced graphical presentation of the cannon plugs and pins to be connected. The other eight tasks use the HMD and an unenhanced presentation of the cannon plugs and pins to be connected.

Performance Measurement

The following guidelines are used by the experimenter to control the data collection:

1. This evaluation is concerned with cannon plug pin selection/connection error rates and task completion times and not the actual operation of the HMD.
2. If a technician is experiencing difficulty in operating the HMD or any of its components the experimenter helps the technician in the proper equipment operation prior to beginning the task.
3. If the HMD or any of its related components fail during the test, or the technician has to stop the test for any reason that test is aborted and the technician's data is eliminated from the analysis.
4. There is no set time limit for task completion.
5. Technicians are allowed only one selection/connection attempt per task.

Conducting the Experiment

Sequence of Events

- Completion of a Human Use Research Committee (HURC) Form.
- Completion of the Personal Background Form.
- Introduction to the experiment, equipment, and test method.

- Hands-on training on the use of the HMD.
- Practice session with the HMD and practice cannon plug.
- Technician performs the sixteen experiment tasks.
- Experimenter debriefs technicians, administers the questionnaire, and conducts the structured interview.

Completion of Initial Forms

The test subjects complete a HURC Form, Appendix F. This form outlines their rights and the test administrators responsibilities as applied to the experiment. The test subjects also complete the Personal Background Form, Appendix E. This form provides demographic data and allows one more check to ensure that the test subject meets the criteria set forth for inclusion in this experiment. The test subjects are then assigned one of the 28 test subject numbers.

Introduction

The technicians receive a description of the purpose and preliminary instructions for the experiment. Preliminary instructions include the responsibility of the test participant, test administrator, and how the collected data is to be used. Technicians are reminded that their participation is on a voluntary basis. Data collected is not associated with their name, only with an assigned test subject number. Task performance and answers to the User Evaluation Questionnaire or structured interview will not affect their job performance ratings in any way. Appendix H contains the instructions that the experimenter will read to the technicians.

Training

Technicians receive initial training on the HMD – its controls, its operation, and its proper wear (Appendix I contains the training instructions).

Practice

Technicians perform four practice test trials using the rectangular breakout box assembly. This practice is intended to allow the test subject to familiarize themselves with the HMD use and experimental procedure. During the training sessions the experimenter is available to answer any questions that arise. After the technician is comfortable in the use of the HMD the experiment begins.

Task Completion

The test subjects perform sixteen experimental tasks, eight tasks each using the two data presentation methods (unenhanced and unenhanced) in a block randomized presentation order. The test administrator steps through the program as the test subject indicates he or she is ready to continue.

Debriefing

After the experiment is complete, the User Evaluation Questionnaire, Appendix A, is completed by the test subject and a structured interview, Appendix B, is conducted. The test subjects are debriefed and reminded not to discuss the context of the experiment with anyone else until all the test subjects are run and all the data is collected (debrief instructions are in Appendix J). Technicians also receive information on how their data from the experiment will be used.

Appendix E: Personal Background Form

Test Subject Number: __________

1. **Time in Service: __________**
2. **Paygrade: __________**
3. **Time at Barksdale AFB: __________**
4. **Are Your Current Primary Duties Performing Maintenance Tasks on the Flightline / Bench?** (i.e. not in an office, support section, QA, or driving a truck)

   YES / NO

5. **Current Continuous Time on the Flightline / Bench: __________**
6. **Current AFSC: __________**
7. **Is Your Eyesight at Least 20/20 Corrected? YES / NO**
8. **If You Wear Glasses, Do You Wear Bifocals or Trifocals? YES / NO**
9. **Any Reason Why You Feel You Can NOT Participate in This Experiment at This Time?**

   YES / NO

Appendix F: Human Use Research Committee (HURC) Form

Test Subject Number: __________

Informed Consent Document for Cannon Plug Pin Selection Performance Evaluation Experiment

1. I ________________ have been asked to volunteer as a subject in the project named above. The purpose of the study is to evaluate the effect that information presented on a monocular Head-Mounted Display (HMD) has on technician performance of cannon plug pin selection and connection tasks.

2. In this study I will be asked to perform cannon plug pin selection and connection tasks. I will be asked to complete a questionnaire regarding the tasks. I will be required to work with a Head-Mounted Display (HMD). The session may be videotaped. The videotape from this session will not be presented or distributed for any purpose other than data analysis. Data from the videotapes will be recorded and the tapes will then be erased immediately after completion of the entire study.

3. My participation will not involve risks greater than I encounter on a daily basis. Potential hazards of looking at a computer screen are possible (i.e. eye strain, headaches). The likelihood of these occurrences is slight.

4. My participation will assist the Air Force Institute of Technology, the University of Dayton Research Institute, and Armstrong Laboratory ensure that collaborative technologies meet the users needs. The ultimate benefit of this study will be to make personnel more effective and make their jobs easier.

5. (i) Records of my participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 U.S.C. 552a, and its implementing regulations.
   (ii) I understand my entitlements to medical and dental care and/or compensation in the event of injury are governed by federal laws and regulations, and that if I desire further information I may contact the BAFB legal office at 456-2561.
   (iii) If an unanticipated event occurs during my participation in this study, I will be informed. If I am not competent at the time to understand the nature of the event, such information will be brought to the attention of my next of kin.
   (iv) The decision to participate in this research is completely voluntary on my part. No one has coerced or intimidated me into participating in this program. I am participating because I want to. Captain Webb, (937) 258-2568 has adequately answered any and all questions I have about this study, my participation, and the procedures involved. I understand that Capt Webb will be available to answer any questions concerning procedures throughout this study. I understand that if significant findings develop during the course of this research which may relate to my decision to continue participation, I will be informed. I further understand that I may withdraw this consent at any time and discontinue further participation in this study without prejudice to my entitlements.

Volunteer Signature ____________________ SSN ________________ Date ___________

Investigator Signature ____________________ Date ___________

Witness: ________________________ Date ___________

Appendix G: Experimenter Observation Form

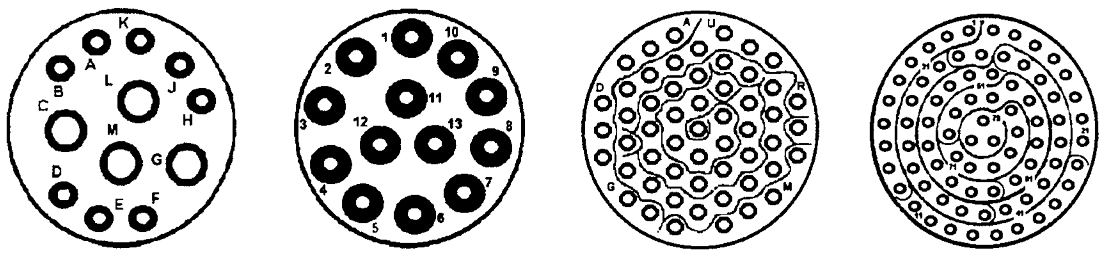
Test Subject Number: ____________

Task Number 1: C E ____________

Task Number 2: C E ____________

Task Number 3: C E ____________

Task Number 4: C E ____________

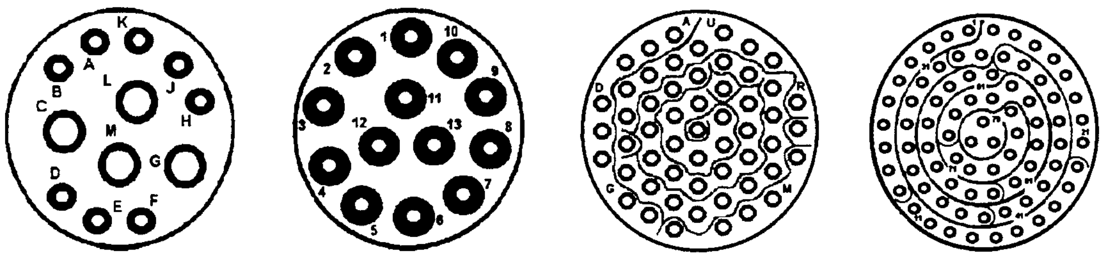


Task Number 5: C E ____________

Task Number 6: C E ____________

Task Number 7: C E ____________

Task Number 8: C E ____________



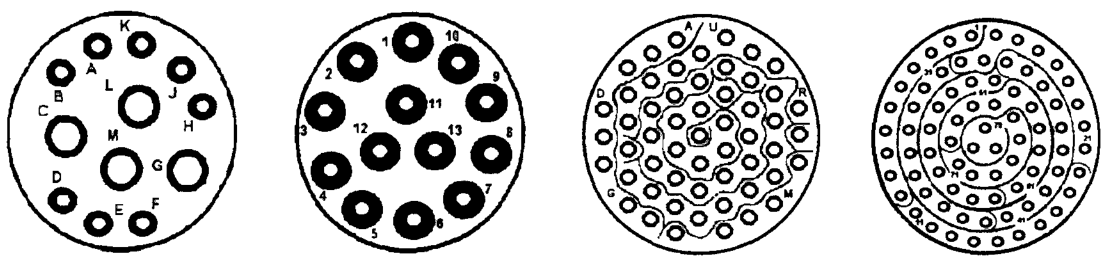
Test Subject Number: __________

Task Number 9: C E __________

Task Number 10: C E __________

Task Number 11: C E __________

Task Number 12: C E __________

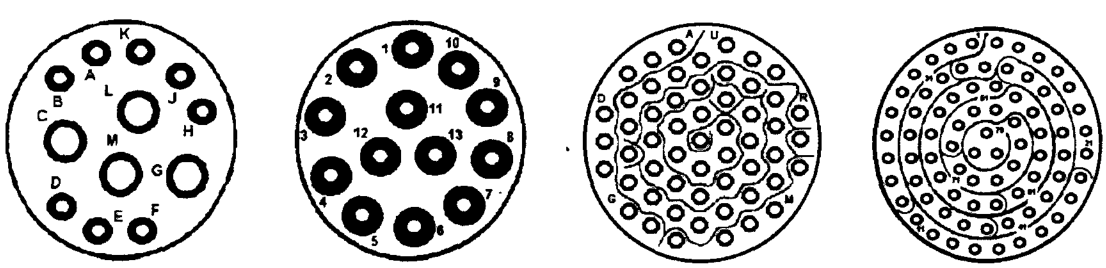


Task Number 13: C E __________

Task Number 14: C E __________

Task Number 15: C E __________

Task Number 16: C E __________



Appendix H: Briefing Instructions

Introduction

Thank you for volunteering to be a test subject in the evaluation of the effect of graphical display enhancements on cannon plug pin selection/connection error rates. I am Captain Robert Webb and I am from the Air Force Institute of Technology at Wright-Patterson AFB, Ohio. Mr. Allen Revels, from the University of Dayton Research Institute, (point to Allen) will be conducting this experiment with me. We are performing this experiment in conjunction with Armstrong Laboratory and the University of Dayton Research Institute, both also at Wright-Patterson. This research will also fulfill my masters thesis requirement.

Purpose

The objective of this research is to study the effect two different graphical data presentation methods using a digital Head-Mounted Display (Hold up the HMD) has on cannon plug pin identification and selection tasks (Hold up one of the Cannon Plugs).

The information obtained form this experiment will be used to support the continued development of digitally displayed maintenance data with the ultimate goal being improved maintenance through the integration of humans and computer technology.

Experiment Description

Avionics maintenance technicians are participating in this experiment. All of the technicians will perform tasks using both presentation methods. All of the technicians will be asked to fill out a HURC Form (hold up a copy of the form). This form spells out your rights and our responsibilities to you for participating in this experiment. Additionally, each of you will fill out a Personal Background Form (hold up a copy of the form). This form documents your military experience and background.

The information collected in this experiment will not be associated with your name, only a test subject number. The data collected will not be related to your job performance, nor will it be released to your supervisors. All data and comments collected will be completely confidential.

Each technician will perform sixteen cannon plug pin selection tasks. Technicians will be required to locate and connect test adapters to specific pins on the test cannon plugs. I will also be taking observation notes while you perform the tasks. Please work as quickly and accurately as possible.

Your test session may be videotaped. If it is, the videotape from this session will not be presented or distributed for any purpose other than data analysis. The videotape will be erased upon completion of the final report of this experiment.

After you complete all of the tasks and the experimental data collection is complete, you will be asked to complete a questionnaire on the HMD and displayed information. I will then talk with you about your observations and impressions of the experiment as a whole.

The test sequence of events will be as follows:

- Completion of a Human Use Research Committee (HURC) Form and Personal Background Form.
- Introduction to the experiment, equipment, and test method.
- Hands-on training on the use of the HMD.
- Practice session with the HMD and rectangular cannon plug.
- Technician performs the sixteen experiment tasks.
- Completion of the User Evaluation Questionnaire, exit interview, and debrief.

Do you have any questions at this time?

Appendix I: Training Instructions

Using the HMD

You will be using a monocular Head-Mounted Display (HMD) as your source of task information for this experiment. I am going to provide you instructions and practice on its basic operation before the experiment gets underway. Please feel free to ask any questions at any time if the instructions and procedures described are not clear.

(Show the technician the HMD and point out the controls as they are discussed.) This is the HMD. It is a back-lit monochrome LCD, which means all information displayed is in shades of gray. The knob directly behind the screen is the contrast knob. The knob to the left of the screen on the head band is the screen intensity knob. The head band can be adjusted using the elastic straps on the head band. This HMD is also equipped with voice input capabilities which we will not be using for this experiment, so the ear piece and microphone on the head band are of no importance. Let's put this on and get you use to wearing it (put the HMD on the technician and allow them to get use to wearing it).

The information that will be presented is completely menu driven (ensure the HMD is on and the program introduction page is showing). You will only need to follow the instructions on the screen and tell us when you are ready to continue.

Cannon Plug Assemblies

Five different cannon plug connector assemblies will be used during this experiment (show them to the technician and tell how many pins are on each). Note that some have the pins numerically referenced and some are alphabetically referenced. Recall that on **alphabetically** referenced cannon plugs the letters **L, O, Q,** *ℓ*, and **o** are not used. The four circular cannon plugs will be used in the experiment itself and the rectangular cannon plug is used for orientation and practice session.

Test Sequence

The test program is a menu driven presentation (show pictures of representative screens as the following sequence is discussed). You will only have to tell us when you are ready to proceed and we will advance the program. The test sequence will start when the "*START*" button is clicked and will conclude when the "*DONE*" button is clicked. (Ensure that the technician can see what is on the HMD screen and understands the instructions being presented.)

The screen before the start of the test will tell you what connector to use. We will give you the proper connector and test adapters. Orient yourself with the cannon plug pin layout and test adapters before telling us that you are ready to continue. The next screen will tell you which pins to connect and provide a graphical depiction of the cannon plug. Connect the pins and tell us when you are completed with the task.

The experiment sequence is:

- Four practice tasks using the rectangular cannon plug.
- Sixteen tasks using the circular cannon plugs.
- Termination of the test sequence.

After completing each task hand the cannon plug assembly, with the test adapters still in place, to me. Again, please work as quickly and accurately as possible.

This concludes the instructions and practice on the use of the HMD and test equipment. Do you have any questions regarding its use before the practice session gets underway?

Appendix J: Debriefing Instructions

Thank you for participating in this experiment. The purpose of this experiment was to compare cannon plug pin selection and connection performance using two graphical presentation methods on a monocular Head-Mounted Display (HMD). The information from this evaluation will be used in future research in support of the selection of a display technology for future weapon systems.

None of the information received or data collected will be associated with your name. Experiment write-ups will describe the data only by test subject number. Do you have any other comments or questions about this experiment?

A copy of the final thesis will be sent to the 2d Bomb Wing so that the participants can read the entire research.

Thanks again for you participation. Please do not discuss any aspect of this experiment with anyone until all of the test data has been collected.

Appendix K: Test Data

The following is the raw test data that was collected at Barksdale AFB, LA in March 1997 along with some initial data analysis.

Raw Error Data

Table 16: Raw Error Data

Test	Trial Number																
Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
2											1						1
3	1					1					1	1					4
4			1										1				2
5				1			1						1				3
6			1					1	1				1	1		1	6
7			1		1												2
9				1		1						1		1			4
10	1									1							2
11				1									1				2
13								1					1				2
14			1			1					1					1	4
15			1	1		1											3
16	1	1													1		3
17		1												1			2
18								1			1	1					3
19			1					1	1						1		4
20				1		1	1	1	1				1			1	7
21																	0
22		1						1									2
23		1															1
24								1									1
26											1			1			2
27		1			1			1	1	1	1						6
28				1				1							1		3
Total:	3	5	6	6	2	5	2	9	4	2	6	3	6	4	3	3	69

* A "1" indicates an error occurred.

* Test Subject Number 1's data was eliminated from analysis because the subject was given the wrong cannon plug for trial number 5. This caused the trial time data to be bad and thus the entire data set to be unused for analysis.

* Test Subject Numbers 8 and 12 were eliminated from analysis because both test subjects indicated that they neither saw nor used the enhanced graphical presentations to locate the cannon plug pins during the test. This invalidated the enhanced comparison of their data and made it unusable for analysis.

* Test Subject Number 25's data was eliminated from analysis because there was an error in the test program sequencing. The test subject received the wrong enhancements and thus the wrong conditions were presented.

Error Data Selection

Table 17: Error Data Selection

Condition	Correct Pin Combinations	Actually Selected Pin Combinations
U2a	A - F	
U2b	D - J	D - H D - L D - L
U2c	E - K	
U2d	D - H	
E2a	A - F	
E2b	D - J	
E2c	E - K	
E2d	D - H	
U3a	9 - 10	
U3b	4 - 12	5 - 12 5 - 12 5 - 12 5 - 12
U3c	2 - 11	3 - 11 3 - 11
U3d	5 - 6	6 - 7 6 - 7
E3a	9 - 10	1 - 10 1 - 10
E3b	4 - 12	5 - 12 5 - 12 5 - 12 5 - 12
E3c	2 - 11	
E3d	5 - 6	
U5a	N - s	N - S N - r N - r N - S P - T N - u N - u
		N - S P - s N - AA N - t
U5b	F - x	E - X F - w F - X F - w F - GG
U5c	C - v	C - T C - V C - x C - V C - V C - V C - V
		C - u C - u
U5d	S - h	S - g H - S S - g
E5a	N - s	M - s L - s
E5b	F - x	F - y F - X
E5c	C - v	C - u C - w
E5d	S - h	S - i
U9a	24 - 46	24 - 43 23 - 36 25 - 46
U9b	15 - 59	15 - 63 25 - 59 13 - 56 16 - 59
U9c	6 - 54	26 - 70 6 - 70 6 - 65 4 - 6 6 - 67
U9d	47 - 67	37 - 57 48 - 51 47 - 51
E9a	24 - 46	
E9b	15 - 59	15 - 39
E9c	6 - 54	6 - 52
E9d	47 - 67	

Raw Time Data

Table 18: Raw Time Data

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time	Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
2	1	TRUE	10	16	5	1	FALSE	4	11
2	2	TRUE	11	9	5	2	TRUE	11	6
2	3	TRUE	16	16	5	3	FALSE	1	17
2	4	FALSE	1	55	5	4	TRUE	6	8
2	5	TRUE	9	20	5	5	TRUE	8	8
2	6	FALSE	6	54	5	6	FALSE	7	10
2	7	FALSE	4	13	5	7	FALSE	2	42
2	8	FALSE	15	13	5	8	TRUE	13	9
2	9	TRUE	13	33	5	9	FALSE	14	11
2	10	TRUE	8	13	5	10	TRUE	12	6
2	11	FALSE	14	44	5	11	TRUE	9	11
2	12	TRUE	7	16	5	12	FALSE	15	16
2	13	FALSE	3	10	5	13	FALSE	5	15
2	14	TRUE	2	30	5	14	TRUE	3	7
2	15	FALSE	5	26	5	15	FALSE	16	7
2	16	FALSE	12	18	5	16	TRUE	10	6
3	1	FALSE	10	32	6	1	FALSE	11	11
3	2	TRUE	13	32	6	2	FALSE	8	16
3	3	FALSE	15	13	6	3	FALSE	5	101
3	4	TRUE	16	12	6	4	TRUE	10	13
3	5	TRUE	7	11	6	5	TRUE	3	7
3	6	FALSE	5	70	6	6	TRUE	4	10
3	7	FALSE	12	20	6	7	TRUE	1	29
3	8	TRUE	14	18	6	8	FALSE	6	92
3	9	FALSE	3	12	6	9	TRUE	14	7
3	10	TRUE	8	8	6	10	TRUE	16	8
3	11	FALSE	1	48	6	11	TRUE	13	13
3	12	FALSE	6	30	6	12	FALSE	15	10
3	13	TRUE	2	16	6	13	FALSE	9	18
3	14	TRUE	11	8	6	14	TRUE	7	9
3	15	FALSE	4	14	6	15	FALSE	12	11
3	16	TRUE	9	23	6	16	FALSE	2	46
4	1	FALSE	5	96	7	1	TRUE	2	23
4	2	FALSE	11	13	7	2	TRUE	4	17
4	3	FALSE	8	11	7	3	TRUE	7	10
4	4	TRUE	10	63	7	4	TRUE	9	11
4	5	TRUE	7	13	7	5	FALSE	6	41
4	6	TRUE	12	14	7	6	FALSE	12	12
4	7	TRUE	9	17	7	7	FALSE	3	15
4	8	FALSE	14	22	7	8	FALSE	13	44
4	9	TRUE	6	31	7	9	TRUE	5	15
4	10	FALSE	13	44	7	10	FALSE	11	6
4	11	FALSE	15	19	7	11	TRUE	16	11
4	12	TRUE	16	16	7	12	TRUE	10	12
4	13	FALSE	2	18	7	13	FALSE	1	17
4	14	TRUE	1	25	7	14	FALSE	8	11
4	15	TRUE	3	12	7	15	FALSE	14	36
4	16	FALSE	4	15	7	16	TRUE	15	21

Table 18 Continued

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
9	1	TRUE	8	9
9	2	TRUE	7	7
9	3	TRUE	5	10
9	4	FALSE	10	20
9	5	FALSE	15	8
9	6	FALSE	1	26
9	7	TRUE	2	17
9	8	FALSE	16	11
9	9	FALSE	4	8
9	10	TRUE	13	17
9	11	TRUE	3	7
9	12	FALSE	14	11
9	13	FALSE	11	10
9	14	FALSE	9	31
9	15	TRUE	6	10
9	16	TRUE	12	10
10	1	FALSE	2	47
10	2	TRUE	4	24
10	3	FALSE	7	26
10	4	TRUE	13	47
10	5	FALSE	12	36
10	6	FALSE	1	61
10	7	TRUE	6	38
10	8	TRUE	3	22
10	9	TRUE	11	11
10	10	FALSE	10	93
10	11	FALSE	16	20
10	12	FALSE	5	110
10	13	FALSE	15	21
10	14	TRUE	8	12
10	15	TRUE	9	27
10	16	TRUE	14	21
11	1	TRUE	12	12
11	2	TRUE	5	32
11	3	FALSE	15	12
11	4	FALSE	10	66
11	5	FALSE	16	38
11	6	TRUE	7	10
11	7	FALSE	13	65
11	8	TRUE	6	64
11	9	TRUE	14	24
11	10	FALSE	8	11
11	11	TRUE	11	12
11	12	TRUE	1	31
11	13	FALSE	2	75
11	14	FALSE	9	41
11	15	FALSE	3	9
11	16	TRUE	4	21

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
13	1	FALSE	14	36
13	2	FALSE	4	13
13	3	TRUE	13	37
13	4	TRUE	7	10
13	5	TRUE	10	9
13	6	FALSE	15	15
13	7	TRUE	16	10
13	8	FALSE	9	29
13	9	FALSE	6	63
13	10	TRUE	5	18
13	11	TRUE	8	10
13	12	FALSE	11	11
13	13	TRUE	2	14
13	14	TRUE	3	6
13	15	FALSE	12	17
13	16	FALSE	1	22
14	1	FALSE	8	14
14	2	TRUE	5	33
14	3	FALSE	10	21
14	4	TRUE	11	15
14	5	TRUE	4	12
14	6	FALSE	13	44
14	7	TRUE	14	11
14	8	FALSE	3	15
14	9	TRUE	9	17
14	10	FALSE	15	14
14	11	FALSE	2	17
14	12	FALSE	16	13
14	13	TRUE	12	8
14	14	TRUE	6	8
14	15	FALSE	1	47
14	16	TRUE	7	9
15	1	FALSE	12	15
15	2	FALSE	15	13
15	3	FALSE	9	13
15	4	FALSE	2	27
15	5	TRUE	4	11
15	6	TRUE	13	33
15	7	TRUE	3	8
15	8	TRUE	6	21
15	9	TRUE	16	9
15	10	TRUE	11	8
15	11	TRUE	5	14
15	12	TRUE	14	10
15	13	FALSE	8	19
15	14	FALSE	7	8
15	15	FALSE	1	22
15	16	FALSE	10	21

Table 18 Continued

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
16	1	FALSE	10	12
16	2	FALSE	11	10
16	3	FALSE	12	19
16	4	FALSE	5	17
16	5	TRUE	4	8
16	6	TRUE	3	7
16	7	TRUE	1	17
16	8	TRUE	6	16
16	9	TRUE	14	18
16	10	FALSE	8	12
16	11	TRUE	13	18
16	12	FALSE	15	20
16	13	TRUE	16	11
16	14	TRUE	7	11
16	15	FALSE	2	38
16	16	FALSE	9	16
17	1	FALSE	12	14
17	2	FALSE	6	53
17	3	TRUE	5	64
17	4	FALSE	3	7
17	5	TRUE	2	51
17	6	TRUE	15	7
17	7	FALSE	9	26
17	8	TRUE	8	14
17	9	TRUE	10	8
17	10	FALSE	16	12
17	11	FALSE	13	26
17	12	FALSE	11	7
17	13	TRUE	1	18
17	14	FALSE	14	31
17	15	TRUE	7	9
17	16	TRUE	4	17
18	1	FALSE	9	30
18	2	TRUE	2	14
18	3	TRUE	7	15
18	4	TRUE	4	19
18	5	FALSE	12	9
18	6	FALSE	3	7
18	7	TRUE	1	25
18	8	FALSE	6	25
18	9	FALSE	8	10
18	10	FALSE	15	14
18	11	FALSE	5	20
18	12	FALSE	10	14
18	13	TRUE	16	7
18	14	TRUE	11	6
18	15	TRUE	13	20
18	16	TRUE	14	6

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
19	1	TRUE	13	38
19	2	FALSE	12	13
19	3	FALSE	11	11
19	4	TRUE	14	16
19	5	TRUE	4	9
19	6	FALSE	5	31
19	7	TRUE	15	10
19	8	FALSE	2	87
19	9	FALSE	3	22
19	10	TRUE	16	11
19	11	FALSE	1	16
19	12	FALSE	6	37
19	13	FALSE	8	11
19	14	TRUE	9	22
19	15	TRUE	7	7
19	16	TRUE	10	8
20	1	TRUE	4	12
20	2	TRUE	14	11
20	3	TRUE	13	29
20	4	FALSE	15	13
20	5	TRUE	3	9
20	6	FALSE	8	12
20	7	FALSE	9	20
20	8	FALSE	2	44
20	9	FALSE	6	9
20	10	TRUE	5	25
20	11	TRUE	16	17
20	12	TRUE	11	10
20	13	FALSE	7	7
20	14	FALSE	12	9
20	15	TRUE	10	12
20	16	FALSE	1	59
21	1	TRUE	12	19
21	2	TRUE	15	7
21	3	FALSE	1	25
21	4	FALSE	2	21
21	5	TRUE	13	18
21	6	FALSE	7	12
21	7	FALSE	4	12
21	8	TRUE	6	11
21	9	TRUE	14	7
21	10	TRUE	3	7
21	11	FALSE	16	8
21	12	FALSE	5	13
21	13	FALSE	10	33
21	14	TRUE	8	8
21	15	TRUE	9	13
21	16	FALSE	11	9

Table 18 Continued

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
22	1	TRUE	5	41
22	2	FALSE	8	28
22	3	FALSE	11	13
22	4	TRUE	6	24
22	5	TRUE	3	8
22	6	TRUE	12	17
22	7	FALSE	13	39
22	8	FALSE	2	33
22	9	FALSE	9	24
22	10	FALSE	7	10
22	11	TRUE	10	13
22	12	FALSE	4	13
22	13	TRUE	16	15
22	14	FALSE	14	26
22	15	TRUE	1	21
22	16	TRUE	15	7
23	1	FALSE	13	41
23	2	TRUE	10	87
23	3	TRUE	8	21
23	4	TRUE	15	13
23	5	FALSE	6	60
23	6	FALSE	4	16
23	7	TRUE	5	23
23	8	FALSE	11	9
23	9	FALSE	9	81
23	10	FALSE	7	8
23	11	FALSE	2	54
23	12	FALSE	12	11
23	13	TRUE	14	29
23	14	TRUE	3	10
23	15	TRUE	1	13
23	16	TRUE	16	9
24	1	FALSE	16	14
24	2	TRUE	2	26
24	3	FALSE	3	10
24	4	TRUE	13	38
24	5	FALSE	9	43
24	6	TRUE	12	10
24	7	TRUE	11	9
24	8	FALSE	10	91
24	9	TRUE	4	7
24	10	FALSE	1	24
24	11	FALSE	7	14
24	12	TRUE	14	10
24	13	FALSE	6	71
24	14	TRUE	15	8
24	15	FALSE	8	11
24	16	TRUE	5	43

Subject Number	Trial Number	Enhanced	Test Set	Elapsed Time
26	1	TRUE	8	15
26	2	TRUE	15	11
26	3	FALSE	13	39
26	4	TRUE	10	33
26	5	FALSE	16	12
26	6	FALSE	3	11
26	7	FALSE	2	44
26	8	TRUE	9	23
26	9	TRUE	12	10
26	10	TRUE	11	10
26	11	TRUE	5	11
26	12	FALSE	14	30
26	13	TRUE	6	18
26	14	FALSE	7	14
26	15	FALSE	1	19
26	16	FALSE	4	8
27	1	FALSE	16	15
27	2	TRUE	10	34
27	3	FALSE	15	11
27	4	TRUE	5	40
27	5	TRUE	3	9
27	6	FALSE	6	39
27	7	TRUE	8	17
27	8	FALSE	13	76
27	9	TRUE	9	50
27	10	FALSE	7	8
27	11	TRUE	2	34
27	12	FALSE	12	18
27	13	FALSE	1	35
27	14	TRUE	4	12
27	15	FALSE	14	42
27	16	TRUE	11	24
28	1	FALSE	4	16
28	2	TRUE	3	10
28	3	TRUE	13	35
28	4	FALSE	10	76
28	5	TRUE	2	10
28	6	FALSE	9	48
28	7	TRUE	12	12
28	8	FALSE	15	21
28	9	TRUE	11	5
28	10	TRUE	1	21
28	11	TRUE	16	9
28	12	FALSE	14	14
28	13	FALSE	8	9
28	14	TRUE	6	9
28	15	FALSE	7	8
28	16	FALSE	5	17

Time Output by Test Subject and Trial

Table 19: Time Output by Test Subject and Trial

Test	Trial Number															
Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	16	9	16	55	20	54	13	13	33	13	44	16	10	30	26	18
3	32	32	13	12	11	70	20	18	12	8	48	30	16	8	14	23
4	96	13	11	63	13	14	17	22	31	44	19	16	18	25	12	15
5	11	6	17	8	8	10	42	9	11	6	11	16	15	7	7	6
6	11	16	101	13	7	10	29	92	7	8	13	10	18	9	11	46
7	23	17	10	11	41	12	15	44	15	6	11	12	17	11	36	21
9	9	7	10	20	8	26	17	11	8	17	7	11	10	31	10	10
10	47	24	26	47	36	61	38	22	11	93	20	110	21	12	27	21
11	12	32	12	66	38	10	65	64	24	11	12	31	75	41	9	21
13	36	13	37	10	9	15	10	29	63	18	10	11	14	6	17	22
14	14	33	21	15	12	44	11	15	17	14	17	13	8	8	47	9
15	15	13	13	27	11	33	8	21	9	8	14	10	19	8	22	21
16	12	10	19	17	8	7	17	16	18	12	18	20	11	11	38	16
17	14	53	64	7	51	7	26	14	8	12	26	7	18	31	9	17
18	30	14	15	19	9	7	25	25	10	14	20	14	7	6	20	6
19	38	13	11	16	9	31	10	87	22	11	16	37	11	22	7	8
20	12	11	29	13	9	12	20	44	9	25	17	10	7	9	12	59
21	19	7	25	21	18	12	12	11	7	7	8	13	33	8	13	9
22	41	28	13	24	8	17	39	33	24	10	13	13	15	26	21	7
23	41	87	21	13	60	16	23	9	81	8	54	11	29	10	13	9
24	14	26	10	38	43	10	9	91	7	24	14	10	71	8	11	43
26	15	11	39	33	12	11	44	23	10	10	11	30	18	14	19	8
27	15	34	11	40	9	39	17	76	50	8	34	18	35	12	42	24
28	16	10	35	76	10	48	12	21	5	21	9	14	9	9	8	17

* The Trial Number time is in seconds. The Test subject's trial times were rounded to the nearest second for analysis purposes

Time Data by Test Condition

Table 20: Time Data by Test Condition

Condition	Pin Combinations	Test Subject Task Time (sec) 2	3	4	5	6	7	9	10	11	13	14	15
U2a	A - F	13	14	15	11			8			13		
U2b	D - J			11		16	11			11		14	19
U2c	E - K	18	20			11	12		36		17		15
U2d	D - H				7			11	20	38		13	
E2a	A - F					10	17		24	21		12	11
E2b	D - J	13	8		8			9	12		10		
E2c	E - K			14	6			10		12		8	
E2d	D - H	16	12	16		8	11				10		9
U3a	9 - 10	10	12				15			9		15	
U3b	4 - 12				10				26				8
U3c	2 - 11			13		11	6	10			11		
U3d	5 - 6	13	13	19	16	10		8	21	12	15	14	13
E3a	9 - 10			12	7	7		7	22		6		8
E3b	4 - 12	16	11	13		9	10	7		10	10	9	
E3c	2 - 11	9	8		6				11	12		15	8
E3d	5 - 6						21						
U5a	N - s			18	42	46			47	75		17	27
U5b	F - x	54	30			92	41				63		
U5c	C - v		32					20	93	66		21	21
U5d	S - h	44		22	11		36	11			36		
E5a	N - s	30	16				23	17			14		
E5b	F - x			31	8			10	38	64		8	21
E5c	C - v	16		63	6	13	12				9		
E5d	S - h		18			7			21	24		11	10
U9a	24 - 46	55	48		17		17	26	61		22	47	22
U9b	15 - 59	26	70	96	15	101			110				
U9c	6 - 54					18		31		41	29		13
U9d	47 - 67			44			44			65		44	
E9a	24 - 46			25		29				31			
E9b	15 - 59						15	10		32	18	33	14
E9c	6 - 54	20	23	17	11		11		27			17	
E9d	47 - 67	33	32		9	13		17	47		37		33

Table 20 Continued

Condition	Pin Combinations	Test Subject Task Time (sec) 16	17	18	19	20	21	22	23	24	26	27	28
U2a	A - F						12	13	16		8		16
U2b	D - J	12		10	11	12		28		11			9
U2c	E - K	19	14	9	13	9			11			18	
U2d	D - H		12				8			14	12	15	
E2a	A - F	8	17	19	9	12				7		12	
E2b	D - J		14				8		21		15	17	
E2c	E - K						19	17		10	10		12
E2d	D - H	11		7	11	17		15	9				9
U3a	9 - 10		7	7	22					10	11		
U3b	4 - 12					7	12	10	8	14	14	8	8
U3c	2 - 11	10	7		11		9	13	9				
U3d	5 - 6	20		14		13						11	21
E3a	9 - 10	7				9	7	8	10			9	10
E3b	4 - 12	11	9	15	7								
E3c	2 - 11			6		10				9	10	24	5
E3d	5 - 6		7		10		7	7	13	8	11		
U5a	N - s	38			87	44	21	33	54		44		
U5b	F - x		53	25	37	9			60	71		39	
U5c	C - v	12		14			33			91			76
U5d	S - h		31					26			30	42	14
E5a	N - s		51	14						26		34	10
E5b	F - x	16					11	24			18		9
E5c	C - v		8		8	12		13	87		33	34	
E5d	S - h	18		6	16	11	7		29	10			
U9a	24 - 46				16	59	25			24	19	35	
U9b	15 - 59	17		20	31		13						17
U9c	6 - 54	16	26	30		20		24	81	43			48
U9d	47 - 67		26					39	41		39	76	
E9a	24 - 46	17	18	25				21	13				21
E9b	15 - 59		64			25		41	23	43	11	40	
E9c	6 - 54				22		13				23	50	
E9d	47 - 67	18		20	38	29	18			38			35

Bibliography

Basta, N. 1995. More-capable operator training programs can help validate plant control systems: A virtual world for operator training. Chemical Engineering, May: 135-138.

Becker, A. 1990. Design case study: Private eye. Information Display, March: 8-11.

Bennett, K. B. & J. M. Flach. 1992. Graphical displays: Implications for divided attention, focused attention, and problem solving. Human Factors, 34 (5): 513-533.

Boles, D. B. & C. D. Wickens. 1987. Display formatting in information integration and nonintegration tasks. Human Factors, 29 (4): 395-406.

Displays: Up Close and Personal, November 1996. WWWeb, http://www.inquiry.com/publication/cmp/OEM/19961101/OEM19961101S0018.htm

Ebeling, C. E. 1997. An introduction to reliability and maintainability engineering. New York NY: McGraw-Hill.

Edwards Evaluation Report, July 1991. San Diego CA: General Dynamics Electronics Division.

Friend, J. A., & R. S. Grinstead. 1992. Comparative evaluation of a monocular head mounted display device versus a flat screen display device in presenting aircraft maintenance technical data. Master's Thesis, AFIT/GSM/LSM/92S-8. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH (AD-A259684).

Galitz, W. O. 1985. Handbook of screen format design. Wellesley Hills MA: QED Information Sciences.

Giese, W. J. 1946. The interrelationship of visual acuity at different distances. Journal of Applied Psychology, 30: 91-106.

Gordon, I. 1968. Interactions between items in visual search. Journal of Experimental Psychology, 76: 348-355.

Gulick, J. G. & E. T. Kell. 1993. Integration of avionics troubleshooting system with interactive electronic technical manuals. Proceedings of the American Helicopter Society 49th Annual Meeting. 863-871.

Hale, S. and D. Piccione. 1990. Pilot performance assessment of the AH-64A helmet display unit. Fort Rucker AL: Essex Corporation (AD-B140472).

Haworth, L. A. and R. L. Newman. 1993. Test techniques for evaluating flight displays. Moffett Field CA: National Aeronautics and Space Administration, Ames Research Center (AD-A260295).

Heleander, M. 1988. Handbook of human-computer interaction. New York NY: Elsevier Science Publisher.

Hibit, R. & D. A. Marx. 1994. Reducing human error in aircraft maintenance operations with the maintenance error decision aid (MEDA). Proceedings of the Human Factors and Ergonomics 38th Annual Meeting. 111-114.

Hunter, J. E., & F. L. Schmidt. 1990. Methods of meta-analysis: Correcting error and bias in research findings. Newbury Park NJ: Sage Publications, Inc.

Keppel, G. & S. Zedeck. 1989. Data analysis for research designs: Analysis of variance and multiple regression/correlation approaches. New York NY: W. H. Freeman and Company.

Kolleck, M. L., Booz, Allen, & Hamilton 1994. Computerized maintenance aid. Aerospace Engineering, Jan/Feb: 7-10.

Kotulak, J. C. and S. E. Morse. 1995. Oculomotor response with aviator helmet-mounted displays and their relation to in-flight symptoms. Human Factors, 37 (4): 699-710.

Krendel, E. S. & J. Wodinsky. 1960. Search in an unstructured visual field. Journal of the Optical Society of America, 50: 562-568.

Langford, J. W. 1995. Logistics principles and applications. New York NY: McGraw-Hill.

Le Beau, R. P. et. al. 1991. Aviation Diagnostics and Maintenance (ADAM) system preliminary concept of operation and functional description. Bethesda MD: David Taylor Research Center (AD-A242598).

Little Displays, Big Images, April 1996. WWWeb, http://www.inquiry.com/publication/cmp/EET/19960429/EET19960429S0058.html.

Masquelier, B. L. 1991. Comparative evaluation of monocular display devices relative to portable computers for display of aircraft maintenance technical data. Master's Thesis, AFIT/GSM/LSM/91S-18. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH (AD-B161858).

Monk, T. & B. Brown. 1975. The effect of target surround density on visual search performance. Human Factors, 17: 356-360.

Montgomery, D. C. 1976. Design and analysis of experiments. New York NY: John Wiley and Sons.

Motorola Shows Virtual Display, September 1995. WWWeb, http://www.inquiry.com/publication/cmp/EET/19950925/EET19950925S0007.html.

Nugent, W. A. 1987. Troubleshooting performance using paper and electronic documentation. San Diego CA: Naval Personnel Research and Development Center (NPRDC TN 87-41).

Payne, D. G. & V. A. Lang. 1995. Mixed versus pure display format in integration and nonintegration visual display monitoring tasks. Human Factors, 37 (3): 507-527.

Quill, L. L., D. E. Kancler, & C. Batchelor. 1996. Ocular dominance effects on the application of monocular, occluding head-mounted displays. Wright-Patterson AFB OH: Armstrong Laboratory, Logistics Research Division.

Quill, L. L., D. E. Kancler, & B. L. Masquelier. 1995. Direct application of wearable computing systems. Wright-Patterson AFB OH: Armstrong Laboratory, Logistics Research Division (SP0900-94-D0001, Task 5).

Raaijmakers, J. G., & W. W. Verduyn. 1996. Individual differences and the effects of an information aid in performance of a fault diagnosis task. Ergonomics, 39 (7): 966-979.

Rash, C. E. and J. S. Martin. 1988. The impact of the U.S. Army's AH-64 helmet-mounted display on future aviation helmet design. Fort Rucker AL: US Army Aeromedical Research Laboratory, Sensory Research Division (AD-A202984).

Schroeder, J. B., G. M. Smith, P. Bursch, & J. W. Meisner. 1992. Field test of an advanced maintenance-system. Proceedings of the Annual Reliability and Maintainability Symposium. 216-222.

Shepherd, W. T. 1990. Human factors in the maintenance and inspection of aircraft. Proceedings of the Human Factors Society 34th Annual Meeting. 1167-1170.

Smith, S. L. 1963. Color coding and visual separability in information displays. Journal of Applied Psychology, 47: 358-364.

Thomas, D. L. 1995. Integrated Maintenance Information System (IMIS): User field demonstration and test: Final technical report. Wright-Patterson AFB OH: Armstrong Laboratory, Human Resources Directorate, Logistics Research Division (AL/HR-TR-1995-0034).

Wagner, D. W. 1977. Color coding -- an annotated bibliography. China Lake CA: Naval Weapons Center (AD-A041061).

Wickens, C. D., D. H. Merwin, & E. L. Lin. 1994. Implications of graphics enhancements for the visualization of scientific data: Dimensional integrity, stereopsis, motion, and mesh. Human Factors, 36 (1): 44-61.

Yonas, A. & J. Pittenger. 1973. Searching for many targets: An analysis of speed and accuracy. Perception & Psychophysics, 13: 513-516.

Vita

Captain Robert R. Webb [redacted] graduation from Danbury-Lakeside High School in Marblehead, Ohio, he entered the Air Force in June 1982. He served as a Precision Measurement Equipment Laboratory Technician until 1989 when he was selected for the Air Force's Airman's Education and Commissioning Program. He graduated from the Ohio State University with a Bachelor of Science degree in Mechanical Engineering in 1992. Robert obtained his commission as a Second Lieutenant upon graduation from Officer Training School on February 3, 1993.

Robert's first commissioned assignment was as an aircraft maintenance officer at Barksdale AFB, Louisiana. During his tour at Barksdale AFB, Captain Webb filled a variety of maintenance positions in support of the B-52H bomber aircraft. These positions included Maintenance Supervisor for the 2nd Maintenance Squadron, and Flight Commander of the 2nd Maintenance Squadron's Aerospace Ground Equipment and Maintenance Flights and the 20th Bomb Squadron's Sortie Production and Generation Flights. Robert received his assignment to the Air Force Institute of Technology in early 1996 and reported in May of that year as a Graduate Acquisition Logistics Management candidate.

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13. ABSTRACT ***(Maximum 200 Words)***
The purpose of this research is to investigate the effects of data presentation methods on technician performance when the procedures are presented on a monocular, head-mounted display (HMD) in a static maintenance environment. This research used two different methods to present the maintenance task data to the technicians. The first method showed the task as it is typically described in standard technical manuals. It described the task to perform and provided a basic picture of the cannon plug to be tested (unenhanced). The second method provided the same information as the first, but it also modified the information by providing visual cues as to which pins were to be selected and connected (enhanced).

United States Air Force avionics maintenance technicians stationed at Barksdale Air Force Base, Louisiana were the test participants in this study. Measurements included task completion time, task error rate, and technician self reports on the HMD usability. The technicians indicated that HMDs could be a useful tool in the performance of their maintenance duties. The data collected during this study indicates that the technicians performed the tasks quicker and committed fewer errors when they used the enhanced graphical data presentation method to perform the tasks.

14. SUBJECT TERMS
Head Mounted Displays, Graphical Enhancements, Error Reduction, Technician Performance Improvement, Cannon Plug Testing, Aircraft Maintenance, Visualization, Technical Orders, Display Devices

15. NUMBER OF PAGES
119

16. PRICE CODE

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AFIT Control Number AFIT/GAL/LAL/97S-5

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