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COMPARATIVE EVALUATION OF A MONOCULAR HEAD MOUNTED DISPLAY DEVICE VERSUS A FLAT SCREEN DISPLAY DEVICE IN PRESENTING AIRCRAFT MAINTENANCE TECHNICAL DATA

THESIS

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COMPARATIVE EVALUATION OF A MONOCULAR HEAD MOUNTED DISPLAY DEVICE VERSUS A FLAT SCREEN DISPLAY DEVICE IN PRESENTING AIRCRAFT MAINTENANCE TECHNICAL DATA

THESIS

Presented to the

Faculty of the School of Systems and Logistics of the

Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Systems Management

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Preface

The U.S. Air Force operates and maintains some of the most sophisticated and complex aerospace vehicles in the world. Technicians maintaining its most advanced aircraft, such as the F-16, B-2, and F-22, are expected to use technical data displayed on electronic media rather than conventional paper Technical Orders (T.O.s). Recent advances in display technology and computer component miniaturization have made it possible to produce fully portable monocular head-mounted display systems as well as standard flat-screen displays. As both types of electronic display devices offer a desirable means for presenting aircraft maintenance technical data to technicians, this research attempted to determine if flightline maintenance performance depends on the display-type used.

So often researchers thank their wives and families last. We feel it appropriate that wives and families receive top billing. We would like to thank Becki Friend and Barbara Grinstead for their unwavering support throughout these arduous times.

We could not have accomplished this thesis without the help and support of many generous individuals. We are indebted to Armstrong Laboratory, Wright-Patterson AFB OH for sponsoring us and providing the equipment. We would like to thank Mr. Bob Johnson, Armstrong Laboratory Branch Chief and Deputy Chief of Maintenance of the 178th Tactical

Fighter Group (TFG), Springfield Ohio Air National Guard (OANG), and Mr. Jerry Brainard of Systems Research Laboratory. A special thanks goes out to Mrs. Barbara Masquelier of Armstrong Laboratory for getting us into this mess and making sure we received the support needed to complete the project.

No experiment can be successfully performed without the generosity of a host. The 178th Tactical Fighter Group graciously provided men, material, and a dedicated commitment to seeing the project through. Specifically, the Avionics and Aircraft Personnel Group shops deserve recognition for allowing us to wreak havoc on their maintenance schedules. Also, MSgt Ralph Wells of the Quality Assurance office deserves singular acknowledgment for bringing all the pieces together.

We would also like to thank our advisors, Maj Jake Simons, and Lt Col Paul Auclair for keeping us from straying from our objective.

Jeffrey A. Friend Randy S. Grinstead

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Abstract

As military developers provide increasingly complex weapon systems, it becomes more difficult for maintenance technicians to perform their jobs. One aspect of the technicians' world is the need to access technical information in the performance of their duties. This study investigated two electronic display systems to evaluate which enhanced technician performance more. A Head Mounted Display (HMD) device and a portable hand-held flat-screen computer were evaluated in the performance of two flightline maintenance activities. Although both display systems were fully portable and self contained, only the HMD system allowed continuous access to technical information during task performance. In most cases, technicians using the HMD system outperformed those equipped with the flat-screen computer system in terms of effectiveness and efficiency.

COMPARATIVE EVALUATION OF A MONOCULAR HEAD MOUNTED DISPLAY DEVICE VERSUS A FLAT SCREEN DISPLAY DEVICE IN PRESENTING AIRCRAFT MAINTENANCE TECHNICAL DATA

I. Introduction

The Need for Research

Today, computer application covers nearly all aspects of society. Methods of displaying information generated by these computers are as diverse as the applications themselves. Typical displays used on Personnel Computers are the desktop monitor and the flip-up display screens used on portable laptop computers. An alternative method of displaying information is the monocular head-mounted display device (HMDD). The HMDD has been used primarily in military aviation. For example, Army pilots flying AH-64 Apache helicopters use HMDD technology for displaying target and flight information. An HMDD is a miniaturized display that presents an image to one of the wearer's eyes. Although the HMDD screen may be physically as small as a one inch by one inch square, its image is equivalent to that presented by a 12-inch computer monitor viewed at two feet (Masquelier, 1991:2). A key attribute of HMDD technology is that it permits ready accessibility to information while allowing both hands to be free to perform an activity. HMDD technology has proven its worth in the cockpit; expansion of HMDD technology into non-flying applications appears to have merit.

Performance Enhancement for Aircraft Maintenance. Civilian aircraft maintenance has become an increasingly difficult activity. Worldwide accidents and incidents attributed to improper "inspection, servicing, and repair of aircraft" are on the rise (Shepherd, 1990:1168). Maintenance concerns within the Federal Aviation Administration (FAA) prompted "a multiyear research program to identify areas where human factors engineering can significantly enhance safety...." (Shepherd, 1990:1167). One of the FAA's primary research areas is the application of advanced technology to aircraft mechanic performance. The increasing complexity of today's aircraft stresses the technician's ability to maintain the equipment. For example, some aircraft are so sensitive that "misapplication of voltmeter leads can cause thousands of dollars of damage" (Shepherd, 1990:1168). The FAA believes that "humans will not be able to meet the growing challenges of aircraft maintenance without the proper application of technology" (Department of Transportation, 1991:105). To compound the problem of increased aircraft complexity, the talent pool from which the airlines and the military can recruit technicians is shrinking (Shepherd, 1990:1169). Therefore, engineers and scientists involved in human factors research should seek to improve the performance of technicians that remain in the career field (Shepherd, 1990:1169).

Becker states that "ready accessibility to hands-free, superimposed information could be invaluable" in applications that relate to patient care in medical settings and to the assembly and maintenance of high cost computers and engines (Becker, 1990:10). The civilian aircraft sector has started to use HMDDs in the ground based aerospace environment for the same reason. For instance, one company is developing an HMDD system for aerospace mechanics. The system allows the mechanic to retrieve instructions or graphics while performing aircraft assembly activities (Schwind, 1990:26).

By using computer systems to display technical data, technicians would be better able to keep pace with the demands of complex aircraft. The FAA wishes to improve upon the current use of "paper" technical information by implementing "computer-based" methods (Shepherd, 1990:1170). Hand-held portable computers and HMDDs could be part of these preferred computer-based methods.

Armstrong Laboratory Mission. The F-16, B-2, and F-22 are but a few of the highly complex aircraft operated and maintained by the US Air Force (USAF). The technicians maintaining these aircraft are expected to use technical data displayed on electronic media (computers with flat screens) rather than conventional paper Technical Orders (T.O.s). In addition to developing the technology needed to display T.O.s electronically, Armstrong Laboratory (AL) has been tasked by the USAF to determine the degree to which alternative methods of presentation enhance maintenance technician performance.

Integrated Maintenance Information System. AL established the Integrated Maintenance Information System (IMIS) effort to determine if more accessible and accurate technical data would improve maintenance technician performance. In developing a flat screen portable computer, the IMIS study determined a limitation.

> The currently envisioned computer will not permit the technician to have technical data available at all times and will not physically fit in all compartments on the aircraft. (Thomas, 1990)

As part of the IMIS effort, AL sponsored a study performed by Barbara Masquelier to investigate an alternative display that would alleviate this limitation. Masquelier's study compared the use of a monocular HMDD to a portable laptop computer, referred to as a Grid computer, in an avionics maintenance, bench-level, repair shop environment.

Masquelier's research objective was to determine the extent of any performance differences between technicians using the two display devices. She found no statistically significant advantages to using one device over the other in a bench-level maintenance task (Masquelier, 1991:67). However, her study also recommended that the two display devices should be tested in a flightline maintenance environment because it would provide a more appropriate test for the HMDD (Masquelier, 1991:66). The HMDD was designed to permit a technician to have both hands free to manipulate the equipment being worked on. It also provides the technician with less restricted mobility to perform the task while the technical data is continuously displayed.

Research Focus

The previous discussion suggested there was a need for a comparative evaluation of display devices being used in the performance of a flightline task. The current research was performed to determine if technician performance improves when aircraft maintenance technical data is presented on an HMDD as opposed to a hand-held, flat-screen device, referred to a Portable Maintenance Aid (PMA). To quantify the concept of performance, the researchers chose to measure task completion times and the number of faults detected. PMA placement was specifically selected to preclude the technician from having continuous access to technical data while performing the maintenance activity.

Scope and Limitations

The HMDD used in the current research was a commercially available Cathode Ray Tube (CRT) display manufactured by Imaging & Sensing Technology. All the other components of the HMDD system were provided by AL. These components were mounted in a lightweight vest, resulting in a fully portable ensemble suitable for flightline applications. A more detailed description of the HMDD system can be found in Appendix A. Another HMDD display, the Private Eye®, was available but not used in this study; its Light Emitting Diode (LED) screen resolution did not meet IMIS requirements. The PMA used in this study was a flat-screen computer that had input keys surrounding a six inch by eight inch Liquid Crystal Display screen. The PMA's physical characteristics can be found Appendix A.

The tasks selected for this study were limited by two factors: the impact of testing on the host organization and the short battery life of the prototype HMDD system. The tasks selected were limited to less than 30 minutes per trial to accommodate the host organization's need to minimize disruption of normal operational duties. Additionally, the HMDD system ran on two rechargeable batteries, which would be completely drained after 30 minutes of operation. AL stated that battery life on production HMDD systems would be improved over the prototype used for this research. Moreover, the combination of an insufficient number of spare batteries and a long charging cycle prevented changing batteries while conducting a trial.

When evaluating electronic media displays, large data bases of technical data that require logical branching to perform the task should be used (Nugent and others, 1987:12). However, the tasks with a high degree of complexity and information branching available for this study would have exceeded 30 minutes and so could not be used.

The location of the current research was the 178th Tactical Fighter Group (TFG), Springfield, Ohio, Air National Guard (OANG). The test article was the A-7D Corsair II attack aircraft assigned to the unit. Two tasks were selected for testing during the current experiment. One task was performed with the test subject seated in the cockpit of the aircraft and the other was performed with the technician inspecting the aircraft engine bay. The maintenance activities available for test were limited to the systems on this aircraft.

Summary

The sections above discuss how computers are becoming more prevalent in the civilian and military sectors. They also suggest that the scope of potential applications is widening due to the need for keeping pace with the ever increasing complexity of today's systems. Both the FAA and the Air Force feel that aircraft maintenance specialists will need computers to aid in maintaining the complex aircraft of the future. This research was conceived to compare promising computer display technologies for such an application. Various other factors shaping this experiment were also outlined. In the following chapter, a presentation of past computer research dealing with aircraft maintenance and its relation to this study is provided. Additionally, a discussion of the interaction between man and computer and the associated advantages and disadvantages of computer use are presented.

II. Background

Overview

The relationship between the human-computer interface and performance potential in a maintenance environment is a complex and largely untested field of study. This chapter will review four areas that influenced the formulation of the current experiment: (1) previous HMDD nonflying experimentation, (2) user performance potential, (3) visual side effects, and (4) display attributes.

Previous HMDD Non-Flying Experimentation

To the knowledge of the current researchers, only two studies have been performed that evaluated the application of HMDD technology to non-flying activities. Both studies compared HMDD systems to flat-screen computer systems in an aircraft maintenance environment. Studies of HMDD applications in flying environments were investigated and determined to be inappropriate due to the vast differences in operating environments. This study concentrated on the impact of HMDD application to activities in a comparatively static environment.

Masquelier Study. The first study to be discussed was performed by Barbara Masquelier in 1991. Masquelier conducted a controlled experiment of two similar bench-top, trouble-shooting tasks using a Light Emitting Diode (LED)

HMDD and a flat-screen device (Grid Computer) to display the technical information. The experiment collected two types of data: (1) observational measurements from the experiment itself and (2) responses from post-test questionnaires and structured interviews. The participants were 16 maintenance technicians (eight experienced and eight less-experienced) from the 4950th Test Wing Communication and Navigation shop (Masquelier, 1991:7).

Masquelier found no statistically significant performance difference between HMDD equipped technicians and Grid Computer equipped technicians (Masquelier, 1991:67). However, her study provided some key elements to the current experimental design: (1) a recommendation for testing flightline activities, (2) identification of technician experience as a possible influence on task completion times, and (3) an assessment of HMDD visual effects on subjects performing in a relatively static environment.

Testing Flightline Activities. The task performed in Masquelier's study was a bench-top checkout and analysis of a radio receiver/transmitter. This type of checkout was considered by the 4950th Test Wing to be representative of the intermediate level maintenance actions it routinely performs (Masquelier, 1991:35). However, the task did not require the technician to move from the workbench to perform the checkout, nor did it require both hands to be free. Masquelier concluded that such a task was not a suitable choice to test a hands-free device that offered the technician a high degree of mobility (Masquelier, 1991:67). Masquelier's assessment was echoed by technicians performing the troubleshooting task. All the technicians agreed that "the tasks selected were not the best possible application for the use of a hands-free display device" (Masquelier, 1991:66). Therefore, further experimentation involving a flightline maintenance task was recommended by Masquelier to better test the HMDD against the portable Grid computer (Masquelier, 1991:66).

Technician Experience. Masquelier's study found that "there was a statistically significant difference for the performance times of experienced and [less-experienced] technicians" (Masquelier, 1991:69). The degree of influence experience has on technician performance will be discussed later in the User Performance Differential section.

HMDD Visual Side Effects. Masquelier's questionnaire and interview data suggested that visual problems such as eye strain, blurring, focusing, capability to switch attention from the display to the work, headaches, and afterimages were not a problem for technicians performing the bench-level test with the HMDD (Masquelier, 1991:73). Moreover, the technicians found both devices suitable for performing maintenance activities, although they preferred to use the Grid computer (Masquelier, 1991:70). Additional discussion of visual side effects is provided after a review of the Edwards study.

Edwards Study. The second evaluation of display devices was a comparative analysis of HMDD and flat-screen technology performed by General Dynamics Electronics Division in November 1990. The study was based on the personal perceptions of aircraft maintenance technicians assigned to the F-16 Combined Test Force organization. The study asked technicians to compare LED and CRT HMDDs to hand-held computers. Technicians "completed a rating scale and commented on open-ended questions" (Edwards Evaluation Report, 1991:16). Their responses were combined and a statistical mean was calculated for each of the question categories.

The Edwards study provided the following key aspects to the design of the current experiment: (1) a measure of display-types' suitability to assist the technician in a maintenance activity (2) a confirmation of the importance of task selection, and (3) an assessment of the visual side effects.

Display Type Suitability. The overall mean rating indicated that both types of devices were found acceptable for displaying technical data in an environment which was not highly dynamic. When the study's 20 technicians were asked which display device they preferred to use, 18 preferred the flat-screen devices, and two preferred the HMDDs (Edwards Evaluation Report, 1991:26). The perceptions of the participants of the Edward's study confirm what the Masquelier study concluded; technicians prefer to use a flat-screen display device over the use of an HMDD. However, both studies provided very little time for technicians to familiarize themselves with the visual demands associated with using an HMDD.

Importance of Task Selection. When the 20 technicians were asked whether they would prefer using the flat-screen device (or PMA) or the HMDD under different circumstances, ten preferred to use the PMA under all conditions. None of the technicians preferred to use the HMDD under all conditions, but ten preferred to have both systems available for all applications (Edwards Evaluation Report, 1991:26). This preference for both display systems suggests that the selection of a display device might be task dependent. Further evidence of task dependency was seen in comments made by the technicians. There were three primary reasons given for preferring the flat-screen devices. The major reason given was the freedom provided by not having anything attached to the body; a technician can lay it aside when not immediately using it. One technician commented that "accessing tight places will make wearing (the HMDD) impractical" (Edwards Evaluation Report, 1991:27). A second reason given was the compactness of the flat-screen devices. The third reason was its ease of use. In contrast, reasons given for preferring the HMDD were characteristic of maintenance activities that differ from activities in which flat-screen systems excel. For example, one reason given was the HMDD would allow the technician to have both hands free for carrying items other than the technical data display (Edwards Evaluation Report, 1991:26). Another technician suggested that the HMDD "might be good for presenting workcards for phase inspection" (Edwards Evaluation Report, 1991:27). Apparently, technician display preference is very much task dependent.

HMDD Visual Side Effects. Some of the participants indicated that they suffered some visual side effects from using the HMDD. The study placed the visual problems into three categories: eye strain, frustration with trying to focus on information, and interference between eye piece and work objects (Edwards Evaluation Report, 1991:23). The study failed to mention the number of complaints associated with the categories. However, the descriptive words used indicated that the participants affected were in the minority.

User Performance Differential

The current study focused on factors that influence technician performance. The interaction between man and machine appears to affect performance differently depending on the experience of the individual and the type of task performed. According to Heleander:

> Users who have acquired extensive knowledge and skill related to a job might be expected to use a computer system on the job more effectively than users with little domain specific knowledge. (Heleander, 1988:557)

Heleander's view appears to be confirmed in Masquelier's study; experienced technicians using the display devices outperformed their less-experienced counterparts.

The Edwards study suggested that the performance of inspection tasks might benefit from using an HMDD, while Drury and others (1989) implied that inspection performance is a function of cognition. Taken together, these studies could be interpreted to infer that cognitive load influences the degree to which electronic display devices enhance technician performance. Hence, cognitive load was considered in selecting the tasks evaluated in the current study.

HMDD Visual Side Effects

Both the Masquelier and Edwards study dealt with possible visual problems that result from using an HMDD in a maintenance environment. The concern over visual problems stems from studies evaluating HMDD technology in a flying environment. A study by Rash and Martin suggested retinal rivalry and a slight decrease in visual resolution might result from using an HMDD in a dynamic environment. Retinal rivalry is the ability to "selectively switch back and forth between the two images being presented to separate eyes" (Rash and Martin, 1988:M-3-9). A Hale and Piccoione study supposed that depth perception difficulties (spatial disorientation) might occur from using an HMDD (Hale and Piccione, 1990:14). The current experimental environment falls between the relatively stable bench-top environment of

Masquelier's study and the highly dynamic environment of a pilot flying a plane. The current study will investigate these potential effects on a technician performing flightline tasks.

The side effects experienced by participants in the studies discussed thus far may have been a function of environmental ergonomic factors. With the help of the American Optometric Association (AOA), Sheedy collected data and ranked the eight most common types of problems associated with working at a Visual Display Terminal. The problems were as follows: (1) eyestrain, (2) headaches, (3) blurred Vision, (4) dry or irritated eyes, (5) neck and/or backaches, (6) photophobia, (7) double vision, and (8) afterimages (Sheedy, 1992:20). Of the total number of responses in the Sheedy study, 37% of the subjects were diagnosed as having problems attributable to environmental factors. The optometrists of the AOA ranked four environmental ergonomic factors as the cause of the problems: (1) screen glare, (2) work arrangement, (3) poor lighting, and (4) screen resolution (Sheedy, 1992:20-21). The environment of the current study addresses these ergonomic factors.

Display Attributes

With regard to the current investigation, the interface between man and machine begins with the display screen, or more specifically, the attributes of the information displayed on that screen. A number of studies have suggested that human performance degrades as the density of information displayed on one computer screen increases (Heleander, 1988:382). When programmers are deciding what information to display, they should display only the minimum amount of information necessary to complete the task. However, there is no established density threshold which should not be crossed (Heleander, 1988:387). Text arrangement is also a concern. Galitz (1985) states: "Reserve specific areas of the screen for certain kinds of information, such as commands, error messages, and input fields, and maintain these areas consistently on all screens."

Presentation, as well as arrangement, of the text is also a consideration. Both upper and lower case letters should be used, as in conventional writing. Text displayed in this manner is read about 13% quicker than text in all upper case (Heleander, 1988:387). Left margin justification and double line spacing should be used. Single spacing is read 11% slower than double spacing. Double spacing should be used between paragraphs also (Heleander, 1988:398-399). Even if the text is arranged as above, a poor quality image will degrade its useability. To facilitate a proper image, the use of a monochrome screen is preferred. This screen permits adequate contrast between the text and the background (Heleander, 1988:437,439).

In the current research, the software (image) provided for both the HMDD and PMA displayed text left justified with upper and lower case letters. The text used single line spacing with double line spacing between steps. Both devices used a monochrome screen with black lettering on a white background. The text was consistently placed in a specific region of the screen with error messages, command lines, and input fields placed in separate areas of the screen. All of these display attributes, except for the single line spacing, should further contribute to performance enhancement. Line spacing was constrained by the software system provided by AL.

PMA Screen Attributes. The screens of large, battery-powered, flat-screen LCDs have historically had contrast limitation problems, resulting in difficulties with certain viewing angles. However, recently developed LCDs don't necessarily exhibit this problem to as great an extent (Heleander, 1988:470). The current study included an evaluation the PMA's contrast capabilities.

HMDD Screen Attributes. Historically, HMDDs have had problems with image quality. The high resolution of a Video Graphic Array (VGA) CRT makes it a suitable choice for displaying pictorial information, alphanumerics and graphics (Tannas, 1985:138). It appears plausible that HMDD image quality may be related to users' susceptibility to eye strain with subsequent headaches and blurred vision. Improved image quality enhances the opportunity for increased technician performance due to the VGA CRT capability to display detailed graphics and high quality text.

Screen fading is another disadvantage associated with electronic displays. Controlling target luminance is a common method of reducing screen fading. However, the display luminance must be set to avoid causing user health problems. In a study performed by Matthews and Mertins (1987), target luminance was tested at various levels normally found on microcomputer display screens. The test period was four hours, the length of time thought equal to half a work day. The study concluded that neither visual performance, nor subjective well-being, were significantly influenced by the screen luminance (Matthews and Mertins, 1987:1275). The screen luminance of the HMDD used in the current study was below the luminance level cited by Matthews and Mertins.

Summary

The research discussed above highlights important items for this study to consider, both from an evaluation and an experimental controls perspective. Factors that would appear to influence performance enhancement include: type of task, technician experience level, and display attributes. Visual side effects also play a major role in the acceptance of the HMDD as a performance enhancement tool. In the methodology chapter to follow, the experimental setup, experimental controls, and method of measuring technician performance are addressed.

III. Methodology

Research Design Strategies

In this study, the relationship between technician performance and the method used to display technical data was researched. To facilitate the research, data had to be collected and evaluated. Several methods of collecting and evaluating data were available. However, constraints quickly diminished the research designs suitable for this study. The primary constraint to using simulation or a parametric study was the limited degree of problem crystallization: the research question lacked sufficient definition to provide the structure required for either of these methods. Furthermore, case studies and surveys were eliminated because the AL-developed HMDD used was the only fully portable HMDD system in the Air Force inventory at the time of this study.

A true experimental design was selected and collection of empirical data was accomplished by direct observation of subjects performing maintenance tasks in a controlled experimental environment. The artificiality of a controlled experiment was minimized by conducting the trials using operational technicians performing standard maintenance activities. The technical information displayed was similar to the T.O. information routinely used by the technicians.

A previous study conducted by Masquelier (1991) used a one-variable-at-a-time empirical methodology to investigate the completion times of bench-top maintenance activities. That study evaluated the influence both technician experience level and display type had in effecting task completion time. Masquelier's study evaluated 16 subjects (eight were experienced and eight were less-experienced) as they each performed two similar tasks for a total of 32 trials (Masquelier, 1991:31). This method was not selected for the current study because it restricted the range of maintenance activities that could be investigated. The two tasks chosen in Masquelier's study had to be essentially equivalent to ensure that the tasks performed had an insignificant influence on the task completion times. Furthermore, her study was limited to two tasks in order to minimize the effect of technician learning on the completion times. The current researchers determined that using the one-variable-at-a-time method would have required reducing the scope of the current investigation.

A factorial design was chosen for this study because it allowed simultaneous manipulation of several treatments (factors). "By a factorial experiment, we mean that in each complete trial or replication of the experiment, all possible combinations of the level of the factors are investigated" (Montgomery, 1976:121). Factorial experiments are the most efficient designs for effects analysis when there is more than one factor being investigated (Montgomery, 1976:121). Factorial designs are commonly used to screen possible factors when research is in the exploratory stage. For the current study, a two-level, full-factorial design was selected. The experiment investigated three independent variables (factors) with two levels for each. This design is called a 2 X 2 X 2 or 2^3 design, which provides the smallest number of treatment combinations with which three factors can be studied in a complete factorial arrangement. (Montgomery 1976:180-181)

An additional benefit of factorial-designed experiments is the ability to evaluate the possible interactions each variable has with regard to the other variables in the design. By contrast, a limitation of the one-variable-at-a-time approach is that each experimental variable is assumed to be independent of the other input variables. "The one-variable-at-a-time method provides an estimate of the effect of a single variable at selected fixed conditions of the other variables (Box, 1978:312)." By using a factorial design, the assumption of variable independence can be empirically assessed.

In summary, a two-level factorial design was selected for studying the relationship between technician performance and the method used to display technical data for the following reasons: (1) fewer trials are required; (2) more factors are explored; (3) there are less restrictive assumptions regarding independence and (4) factorial design is more efficient at screening the influence of several variables on the dependent variable.

Experimental Design

The first step in defining the experimental design was to determine the responses to be measured. The research question considers the impact of several factors on technician performance. Thus, this study selected two measures to assess technician performance. The first measure, task completion time, relates to performance efficiency. The second measure, number of faults found, relates to performance effectiveness. To obtain a measure of the participants' attitudes and perceptions, each technician was surveyed and subsequently interviewed to ascertain their opinions on the use of both the PMA and HMDD. The survey and interview questions are included in Appendices B and C, respectively. Additional data, obtained to supplement the quantitative and qualitative results, included a background questionnaire (see Appendix D), a visual resolution test, and an eye dominance exam. The background questionnaire obtained information on previous job experience, while the visual resolution test measured the corrected far vision of the participants. Technicians wearing glasses were tested with their glasses on since they would be wearing them during the experiment.

The second step in defining the experimental design was to select the experimental factors and their respective levels. A factor is defined as the characteristic that differentiates the treatments or populations from one another. The different treatments or populations are referred to as the levels of the factor (Devore, 1991:371). This study investigated three separate factors. They were: (1) type of display device, (2) subject experience level, and (3) type of task. For the purpose of defining the two-level factorial experiment, each factor was evaluated at a high (+) and a low (-) level. The display device was either an HMDD system (+) or a PMA system (-). Subject experience level was categorized as experienced (+) or less-experienced (-). The type of task was categorized as procedural (+) or inspection-oriented (-). An example of a procedural task would be a step-by-step test procedure on a system in which the technician would be required to recognize when hardware responses deviate from normal operating ranges. An example of an inspection oriented task would be a visual inspection of a system or systems. The technician would be provided with a checklist specifying the hardware items to visually inspect and the properties that would cause the items to be identified as discrepant.

Sample size was constrained by the availability of technicians certified in the selected tasks. The experimental plan was for three replications of the eight runs required to fully evaluate the three factors. Therefore, each technician would perform one trial for a total of 24 runs. (However, five additional trials were ultimately accomplished as more technicians became available for testing, resulting in a total of 29 runs.)

Factorial Fundamentals

A few definitions are necessary to understand the process of analyzing a factorial experiment. Factors and levels have been discussed above. The two types of results that are calculated using data obtained from a factorial experiment are main effects and interaction effects. An interaction between factors occurs if the effect of one factor is not the same at all levels of the other factors (Montgomery, 1976: 197). A main effect is the average effect of that factor over all conditions of the other variables (Box, 1978:309). An interaction effect is defined as the difference in response between the levels of one factor due to the varying of the other factors (Montgomery, 1976: 122).

> Interactions occur when the effect of one variable is not completely independent of other variables. That is, when the effect of one variable on the outcome of the experiment is a function of the level of the other variables. (Pappas, 1991:49)

Interaction effects play a major role in evaluating the main effects. "A significant interaction can tend to mask the significance of main effects" (Montgomery, 1976: 123). As a result, "the main effect of a variable should be individually interpreted only if there is no evidence that the variable interacts with other variables" (Box, 1978: 317).

Finally, the design matrix is the medium that draws the factors, their levels, the main effects, and the interaction effects together. Montgomery (1976:188) writes:

> The following table illustrates the treatment combinations required to evaluate fully the first order effects of a 2^3 factorial design. Each factor A, B, and C is evaluated at two levels, a high and low level. These levels are represented by (+) for high and (-) for low and can be quantitative or qualitative in nature.

2^3 FACTORIAL DESIGN MATRIX

Treatment				Factorial Effect				
Combination	I	A	B	AB	C	AC	BC	ABC
1	+	-	-	+	-	+	+	-
2	+	+	-	-	-	-	+	+
3	+	-	+	-	-	+	-	+
4	+	+	+	+	-	-	-	-
5	+	-	-	+	+	-	-	+
6	+	+	-	-	+	+	-	-
7	+	-	+	-	+	-	+	-
8	+	+	+	+	+	+	+	+

The heading for each column represents the effect being evaluated. A factor effect is represented by the change in the output variable response when that factor is varied from the low level (-) to the high level (+) (Box, 1978:309). An effect is considered significant when its absolute value is significantly different from zero. The I term is a measure of the mean response. The A, B, and C terms represent the main effects, which are calculated by subtracting the average value of all results for which the particular variable was low (-) from those for which the particular variable was high (+). The AB, AC, BC, and ABC terms are called the interaction effects. The calculation of the interaction effects was the same as for the main effects. A low level interaction effect was represented when the product of the levels for the associated factors was negative. A high level was represented when the product of the levels for the associated factors was positive. For example, both (+,-) and (-,+,+) would be representative of a low lev· l interaction. Conversely, an example of a high level interaction would be represented by a (-,-) or (+,-,-). (Box, 1978:310)

Each row in the matrix represents an experiment with the conditions specified by the (+) or (-) under the appropriate column factor. For example, the first trial in the matrix would be based on having all the factors at their low (-) level.

To determine if the effect is significant, the variance of the effect must be determined. Generally, the variance of the effect can be expressed as:

$$Var(effect) = 4\sigma^2/N \qquad (1)$$

where σ^2 is approximated by S^2, the pooled estimate of the run variance, and N is the total number of runs. This formula applies when the sample sizes (or degrees of freedom) for each row (design point) are equal. (Box, 1978:320)

Obtaining a pooled estimate of the variance requires that runs be replicated at one or more design points.

> In general, if g sets of experimental conditions are genuinely replicated and the n_i replicate runs made at the i^{th} set yield an estimate S_i^2 of σ^2 having ν_i equals n_i-1 degrees of freedom, the pooled estimate of run variance is

$$S^2=\frac{\nu_1 S_1^2+\nu_2 S_2^2+\cdots+\nu_g S_g^2}{\nu_1+\nu_2+\cdots+\nu_g} \qquad (2)$$

with $\nu = \nu_1 + \nu_2 + \ldots + \nu_g$ degrees of freedom.

(Box, 1978:319)

The pooled estimate S^2 can then be used as an approximation of the total variability, σ^2, affecting runs made at the different experimental conditions. The variance of the effect can be determined with Equation 1 using the pooled estimate of the run variance and the total number of trials performed. The standard error of the effect can be found by taking the square root of the variance of the effect. (Box, 1978:319) The level of significance was set at approximately .05 using 2σ as the critical value.

Experimental Subjects and Tasks

The 178th TFG, Springfield, OANG, which flies the A-7D attack aircraft, was selected to support this experiment. The organization selected had to: (1) be representative of an operational flying unit, (2) have a sufficient number of maintenance technicians available to support experimental requirements, (3) have technicians with a wide variety of experience levels, and (4) routinely perform flightline maintenance activities. OANG at Springfield met these requirements. An operational flying unit was selected to increase the generalizability of the experiment. The requirement for a wide variety of experience was designed to maximize the contrast between the two levels of the experience factor. Similarly, the requirement for routine performance of a flightline maintenance activity was intended to increase the applicability of the study to other maintenance organizations.

The selected tasks would be a critical factor in successfully answering the research question. The task selection process was conducted using subject matter experts (SMEs). SME technicians from the 178th TFG OANG provided a list of 14 tasks for consideration. The tasks were inherently limited to those conducted by the 178th, the participating maintenance organization.

The selection of the tasks was based on the following characteristics: (1) approximate completion time for the task, (2) visual access to a hand-held computer while performing the task, (3) the degree of difficulty in gaining access to the technical data displayed by the PMA, (4) the degree of reliance on technical data required to complete the task, (5) the representativeness of the task to common tasks performed in a field environment, (6) the time required to have both hands free to complete the task, (7) the number of times the candidate task is performed on a normal basis, and (8) the degree to which the task can be performed by one technician.

Maintenance Evaluation Board. After receipt of candidate tasks, a maintenance evaluation board composed of experts from the Air National Guard, AL Human Factors

Engineers, AFIT faculty from the School of Systems and Logistics and the School of Engineering, and the current researchers evaluated the 14 proposed tasks based on the criteria described above.

Some of the maintenance activity types rejected by the board were short-duration remove-and-replace activities, troubleshooting activities, and tasks requiring a two-man team for safety reasons. Remove-and-replace tasks of approximately 30 minutes duration were not selected because they could be completed without reliance on technical data. Troubleshooting tasks were not selected because task completion times were driven by factors other than the type of display device. Tasks requiring two technicians due to a two-man safety policy were eliminated because there was an insufficient number of technicians to support the desired replications. The board determined that inspection and procedural system checkouts were the best suited of the candidate tasks to evaluate the effects of experimental treatments.

Procedural Task Selection. The board selected the operational checkout of the A-7D's APQ-126 radar. For the remainder of this study, this task will be referred to as the Fault Isolation Test. The technical data for the task was extracted from T.O. 1A-7D-2-14-3. The task technical data was tailored to reduce the task completion time to approximately 30 minutes. The data for this test is shown in Appendix E. Activities outside the cockpit and activities requiring a second technician were either eliminated, as previously mentioned, or performed by the current researchers. The tailoring resulted in a task that could be performed by a single technician seated in the cockpit.

In the Fault Isolation Test, the researchers disconnected a co-axial cable on the radar assembly under the nose radome of the aircraft (see Figure 1). The disconnected cable was not within the test subject's view at any time prior to or during the experiment. The fault could only be detected by following the technical data displayed and, hence, provided a means of assessing how closely the test subjects followed the technical data. The number of participants who missed the inserted fault was recorded and used as a measurement of technician performance.

Figure 1. Location of Fault Isolation Test Fault

__Inspection Task Selection__. The board selected the inspection of the A-7D's engine bay to represent the inspection task. This task will be referred to as the Engine Bay Inspection. The engine bay inspection is performed on the aircraft's structure and subsystems as part of the aircraft phase inspection. During the phase inspection, the Allison TF-41 engine is removed to allow access to the compartment. Tailoring of the inspection task reduced task completion time to approximately 30 minutes and limited personnel to one specialty. This checkout normally involves several different specialty shops, such as Hydraulic, Electrical, Instrumentation, Environmental, Propulsion, and Aircraft Personnel, General (APG). In the current research, the inspection was performed by APGs in accordance with workcards, T.O. 1A-7D-6WC-5. Specifically, the three cards selected were 1-006 (fuel system), 1-014 (throttle cables), and 1-016 (fire detection system). The tailored data is shown in Appendix E. All three subsystem inspections were performed inside the engine bay.

In the Engine Bay Inspection, the inserted fault was a fire detection sensor wire loosened from the retainer clamps (see Figure 2). The inserted fault was an obvious discrepancy among many already existing in the test article engine bay. The validity of the numerous existing faults was verified by a Quality Assurance inspector from the 178th Organizational Maintenance Squadron. As with the Fault Isolation Test, the inserted discrepancy was input to help

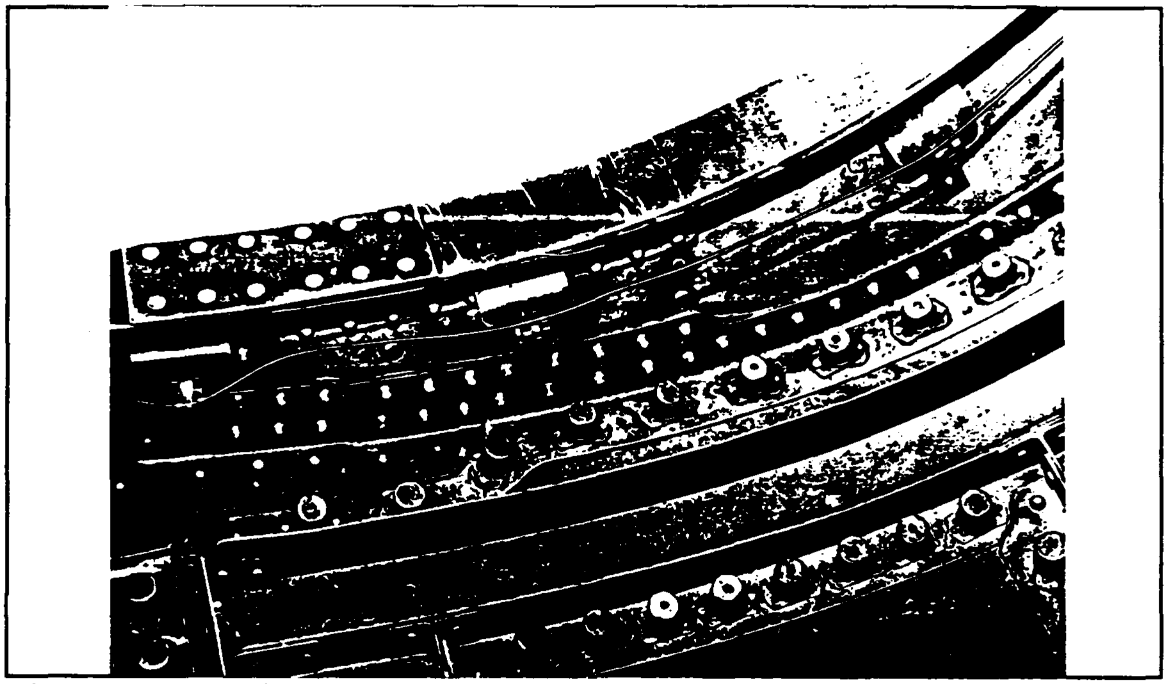

Figure 2. Engine Bay Inspection Inserted Fault

determine how closely test subjects followed the technical data displayed.

Tailoring the procedures provided an added benefit. Technicians with previous exposure to the tasks could not perform the tailored tasks without relying on technical data.

Experimental Controls

Precautions were taken in order to obtain valid data. The types of controls placed on the experiment fell into two categories: those affecting the task completion times and those affecting the performance of the tasks.

Completion Time Controls. Task completion times did not depend on the technician finding the inserted fault. Since the number of test subjects were limited, this provided a reasonable assurance that each experimental run would yield valid data. Task completion time was determined by observing when the technician completed all of the steps displayed on the last screen. To reduce possible error in task time measurement, two timers were used to record the task completion time. The times were averaged for each run unless discrepancies in performing the timing were apparent.

The PMA provided for this experiment was an early prototype. As a result, the screen retrieval times were substantially different between the HMDD and PMA. This was not a constraint of flat-screen systems in general. Subsequent PMA models have comparable processing times to the HMDD. Screen retrieval times would have been essentially the same for the PMA used in this study if it had been constructed with a comparable Central Processing Unit (CPU). Therefore, adjustments to recorded task completion times were made by the researchers to insure the experimental results did not reflect any differences due to the separate computer CPUs. These adjustments were accomplished by taking time measurements of the HMDD and PMA response times in retrieving T.O. data to their screens. Retrieval rates were dependent on the amount of text to be displayed. Therefore, each technician's selection of screens during the experimental run was recorded. Of particular importance were the instances in which the technicians backed up to view the previous screen. The task completion times for each experimental run were then corrected to reflect only the time displayed data was available to the technician. This was accomplished by subtracting out screen retrieval times.

Task Controls. Each technician was required to perform exactly the same steps. Therefore, technicians who identified the fault completed the same number of steps as technicians who did not identify the fault. Placement of the computers was consistent for all runs. The PMA was placed on a tool tray for the Fault Isolation Test (see Figure 3) and on the ground beneath the engine bay for the Engine Bay Inspection.

Maintenance activities selected were tailored to insure that the test instructions were not the same as the T.O.s from which they were extracted. For instance, in the Fault Isolation Test, the frequency check was performed in a

Figure 3. PMA Placement for Fault Isolation Test nonsequential order to increase the cognitive requirements of the test.

Presentation of the task instructions was standardized for all subjects and verified by three pilot studies. The pilot studies were performed using subjects from the intended test population.

To reduce the potential for bias; briefing, training and debriefing instructions (in the form of prepared scripts) were issued before and after the experimental runs to all test subjects (see Appendices F, G, and H).

Test subjects were concentrated into four separate groups. The less-experienced and experienced technicians from the OANG avionics shop comprised two groups. The less-experienced and experienced technicians from the OANG APG shop comprised the other two groups. The less-experienced technicians were the "traditional guardsmen" who performed OANG duties two days a month and during a two-week period once a year. Experienced technicians were full-time OANG employees. Care was taken in evaluating the amount of expertise each guardsmen possessed. If, for example, a traditional guardsmen had a background similar to a full-time technician's experience on the system being tested, the technician was reclassified as experienced. All the technicians were randomly assigned to the type of display used in performing the trial.

The current researchers performed all of the data collection activities to reduce data recording error and, more importantly, to insure consistent qualitative observations. Finally, the technical data displayed and software used to present the data on both the HMDD and PMA were identical.

Calculating the Effects

To better understand how the quantitative findings were obtained, the following section will outline the process used in calculating the effects for the task completion times of the total sample.

The first step was obtaining and recording the raw completion times for the 29 trials performed (see Appendix I). Times initially recorded as minutes and seconds were converted to minutes and tenths of minutes to simplify calculations. The difference in response rates was then subtracted out as previously explained. This was done individually for each trial since some test subjects performed a different number of screen retrievals. The recorded sequence of data retrieval (including backing up to review data) was compiled to determine the time differential for each trial. Corrected data can be found in Appendix J. The next step was to gather descriptive statistics of the sample data. These statistics are shown in Table 1.

Each trial was performed at a prescribed level of each factor being investigated. The level of each factor was represented in the standard factorial matrix by a +1 or -1. If the trial involved a high level of the factor, the matrix

Table 1
Descriptive Statistics of Task Completion Times

	Exp 1 HMDD 1 Insp -1	Exp 1 PMA -1 Insp -1	Exp 1 HMDD 1 Test 1	Exp 1 PMA -1 Test 1
MEAN	22.55	25.20	13.28	14.33
VARIANCE	43.16	15.51	1.08	9.77
	LesExp -1 HMDD 1 Insp -1	LesExp -1 PMA -1 Insp -1	LesExp -1 HMDD 1 Test 1	LesExp-1 PMA -1 Test 1
MEAN	23.78	19.75	16.93	23.99
VARIANCE	45.16	20.04	8.50	18.15

designator was a +1. If the trial involved a low level of the factor, the matrix designator was a -1. Table 2 provides the conversion from category to matrix representation.

Table 3 is a representation of the factorial matrix used in this study to calculate the effects of each factor

Table 2
Category to Matrix Conversion

Factor 1: Level of Experience	Experienced	+1
	Less-experienced	-1
Factor 2: Type of Display	HMDD	+1
	PMA	-1
Factor 3: Type of Task	Test: Fault Isolation Test	+1
	Insp: Engine Bay Inspection	-1

Table 3
Factorial Matrix for Task Completion Times

MEAN	EXP	DISP	TASK	EXP DISP	EXP TASK	DISP TASK	EXP DISP TASK	AVG OBS
1	-1	-1	-1	1	1	1	-1	19.75
1	1	-1	-1	-1	-1	1	1	25.20
1	-1	1	-1	-1	1	-1	1	23.78
1	1	1	-1	1	-1	-1	-1	22.55
1	-1	-1	1	1	-1	-1	1	23.99
1	1	-1	1	-1	1	-1	-1	14.33
1	-1	1	1	-1	-1	1	-1	16.93
1	1	1	1	1	1	1	1	13.28
8	4	4	4	4	4	4	4	
-19.97	-2.27	-1.68	-5.69	-0.17	-4.39	-2.37		

and interaction term for the task completion times of the total sample. At the top of the matrix are the various main and interaction effects being investigated. The first term, MEAN, is an average value and is useful in scaling the importance of the effects values. EXP refers to the main effect, level of experience, and its influence on the total task completion time. DIS refers to the display type main effect. TSK refers to the main effect for the type of task performed. In addition, three two-factor interactions and one three-factor interaction term are displayed at the top of the 2^3 factorial design matrix. The sample means were placed adjacent to the row in the factorial matrix that represents the conditions under which the output data was collected. For example, in the first row of the table, 19.75 was the mean completion time for less-experienced technicians using the PMA for the Engine Bay Inspection.

Table 3 provides an arithmetic guide in calculating each of the effects. Calculating the effect of a factor is a simple matter of (1) assigning the appropriate sign (+,-) of the effect to the observed value for that row, (2) summing the modified observation column, and (3) dividing this sum by the divisor displayed in the next-to-last row of the column.

In order to determine the significance of an estimated effect, an estimate of its variance needs to be determined as previously described. First, a pooled estimate of the run variance is obtained using Equation 2 as described in the factorial fundamentals section of this paper. Then the variance of the effect is calculated using the pooled estimate of the run variance and the number of trials.

This can be performed in one of two ways depending on the type of sample sets being used. If the sample sets are balanced, in other words, the number of observations at each design point are equal, Equation 1 can be used. If the sample sizes are not balanced, another expression of the same concept must be used. Since the estimate is a linear combination of the observed values (which are random samples), the variance of the effect is the variance of the linear combination. As a result, the variance of effect expression is dependent upon the number of design points and replications for each sample set. In the case of the task completion times for the total sample used in this research, the variance of the effect would be expressed as;

$$Var(effect) = \frac{3(\sigma^2/3) + 5(\sigma^2/4)}{16} \qquad (3)$$

This expression is based on a total sample consisting of three design points containing three replications and five design points containing four replications. The pooled estimate of the run variance (Equation 2) was still used for an approximation of σ^2. Table 4 contains the variance values calculated for the task completion times of the total sample.

Table 4
Estimation of Standard Error

Pooled Estimate	21.57
Variance of Effect	2.98
Standard Error	1.73
2* Sigma	3.46

Effect significance was determined by evaluating the effect's value compared to two times the standard error (the square root of the variance of the effect). This level of significance is approximately equal to a 95% level of confidence.

Summary

This chapter introduced the method used to evaluate the data collected and the rationale for selecting the experimental design, the tasks performed, and experimental controls. The main factors used in the design were display type, technician experience level, and task type. In the next chapter, the experimental findings are presented.

IV. Findings

Overview

This study used two quantitative measures (task completion times and number of faults found) and two qualitative measures (survey responses and interview responses) to evaluate technician performance. The experiment described in Chapter 3 was conducted to obtain task completion times to quantify the efficiency of technician performance. The number of faults found was collected to quantify the effectiveness of technician performance. Post trial survey and interview responses were used to evaluate technician perceptions of the display devices.

This chapter was structured to address the measures used in the study: completion times, faults found, survey responses, and interview responses. These measures are preceded by a description of the actual testing environment to provide a better understanding of findings. The analysis of the completion times was broken into three categories; (1) task completion time for the Fault Isolation Test, (2) task completion time for the Engine Bay Inspection, and (3) task completion time for the total sample. Analysis of the number of faults found was broken into two categories; (1) number of faults found for Engine Bay Inspection and (2) missed detection of inserted faults for both tasks.

How the Experiment was Performed

Thirty-one experimental runs were attempted over a period of three weeks. Twenty-nine experiments were successfully conducted. One experiment was aborted due to a technician's inability to read the HMDD screen. The technician was farsighted, normally wore reading glasses, and did not have them available at the time of the test. The other experiment was aborted because a less-experienced technician could not correctly identify the cockpit switches needed to perform the task. Both technicians did complete the questionnaire and interview process.

The 31 technicians came from two different shops. The avionics shop personnel performed a portion of the Fault Isolation Test of the A-7D APQ-126 radar system. The personnel from the APG shop performed a portion of an Engine Bay Inspection normally conducted on the A-7D airframe during a phase inspection. Each maintenance technician performed his associated maintenance task once.

Because of the limited availability of traditional guardsmen, the testing sequence was organized to test homogenous groups of subjects. For instance, all the less-experienced avionics technicians performed the procedural task during a two-day weekend. Testing of all less-experienced APG technicians performing the inspection task was conducted during the following two-day weekend. Testing of experienced technicians was conducted over a six-day period, with avionics and APG technicians tested on separate days. This testing sequence was necessary to minimize the impact on OANG workload.

The type of display used during each trial was randomly selected at the beginning of the day. Some substitutions were made during the testing day when either both sets of HMDD batteries required recharging or the PMA required a cooling-down period. The internal components of the prototype PMA heated up, causing the display screen to lock. To free up the screen, the PMA had to be turned off until the components had cooled down.

Some visual problems were found in using the HMDD with both less-experienced and experienced technicians. Specifically, the HMDD test hardware was not easily adaptable for the technicians with farsighted vision or for the ones who wore bifocal corrective lenses. Even though the visual problems did not adversely effect the performance of any participant, the limited adaptability of the HMDD used in this study adversely influenced the technician's perceptions.

Task Completion Times for the Fault Isolation Test

Figure 4 displays the factor effects on the task completion times for the Fault Isolation Test. The effects were determined using a 2^2 factorial analysis on 13 of the 29 total trials. The factorial analysis can be found in Appendix K. Two times the standard error, indicated by the

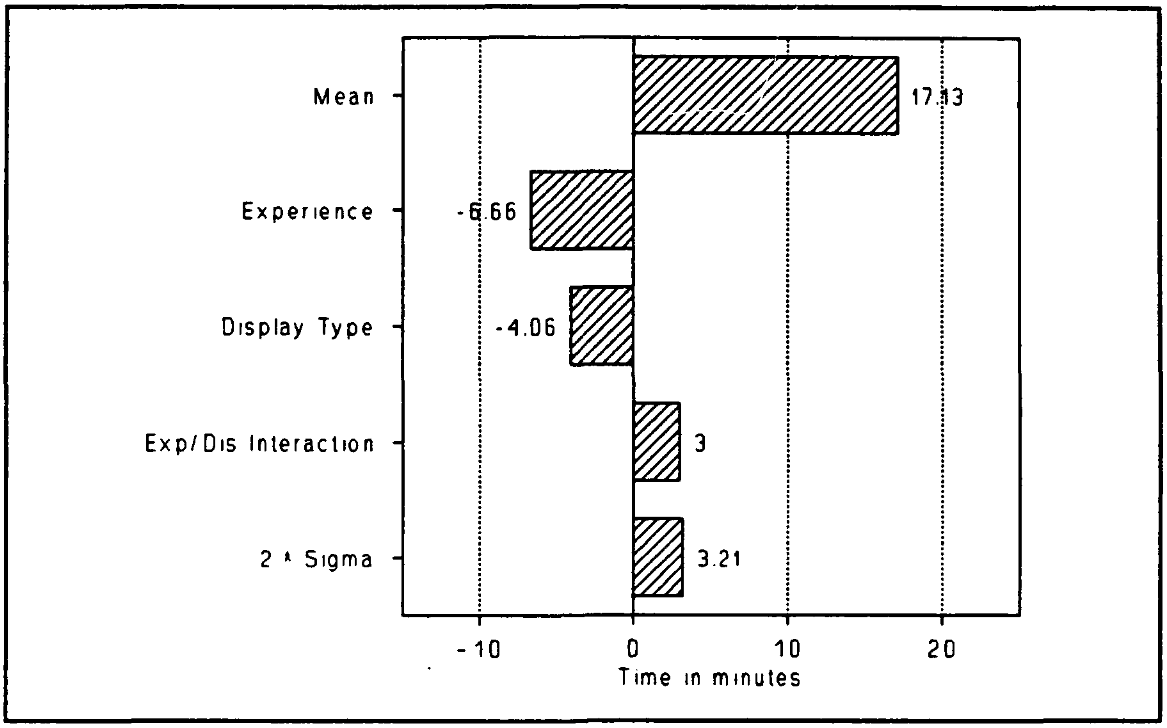

Figure 4. Task Completion Times for Fault Isolation Test

2 * sigma in the figure, was used as a benchmark to gauge the factor effects' significance. The average length of time required to complete the Fault Isolation Test was 17.13 minutes.

<u>Main Effects</u>. Both main effects (experience and display type) were considered statistically significant. The experimental results suggest the experience level had more of an influence in reducing the completion times than display type used (-6.66 minutes versus -4.06 minutes). A negative effect is an indication that the high-level factor had a shorter time than the low-level factor. In this case, the experienced technicians were able to complete the task faster than the less-experienced technician on average.

Technicians using the HMDD finished the task quicker on average than their counterparts using the PMA.

Experience/Display Interaction Effect. The experience/display interaction effect was slightly less than the 2σ threshold. The researchers deemed that the interaction effect was significant enough to warrant discussion. Note the points representing completion times in Figure 5. The points for the less-experienced technicians are spaced farther apart than the points for the experienced technicians. The less-experienced, HMDD-equipped technicians performed the task 7.06 (23.99 - 16.93) minutes faster than their PMA-equipped counterparts on average. The time difference resulting from experienced technicians performing the Fault Isolation Test favored the

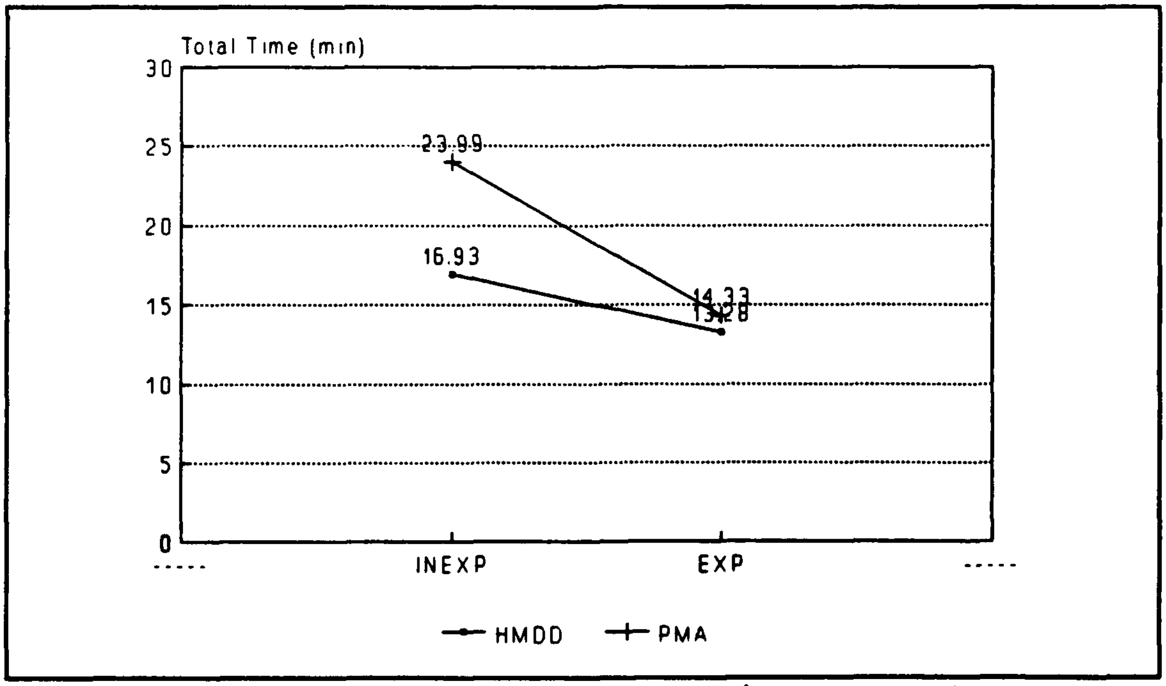

Figure 5. Experience/Display Interaction for Fault Isolation Test

use of the HMDD over the PMA by 1.05 (14.33 - 13.28) minutes on average. The HMDD tended to influence the less-experienced technicians' task completion time on the Fault Isolation Test more than that of the experienced technicians. This observation was confirmed by positive sign of the experience/display interaction effect shown in Figure 4.

Task Completion Times for the Engine Bay Inspection

Figure 6 displays the factor effects on the task completion times for the Engine Bay Inspection. The associated 2^2 factorial analysis was based on 16 trials and is located in Appendix L. On average, the technicians performed the inspection in 22.82 minutes. None of the factors were considered significant.

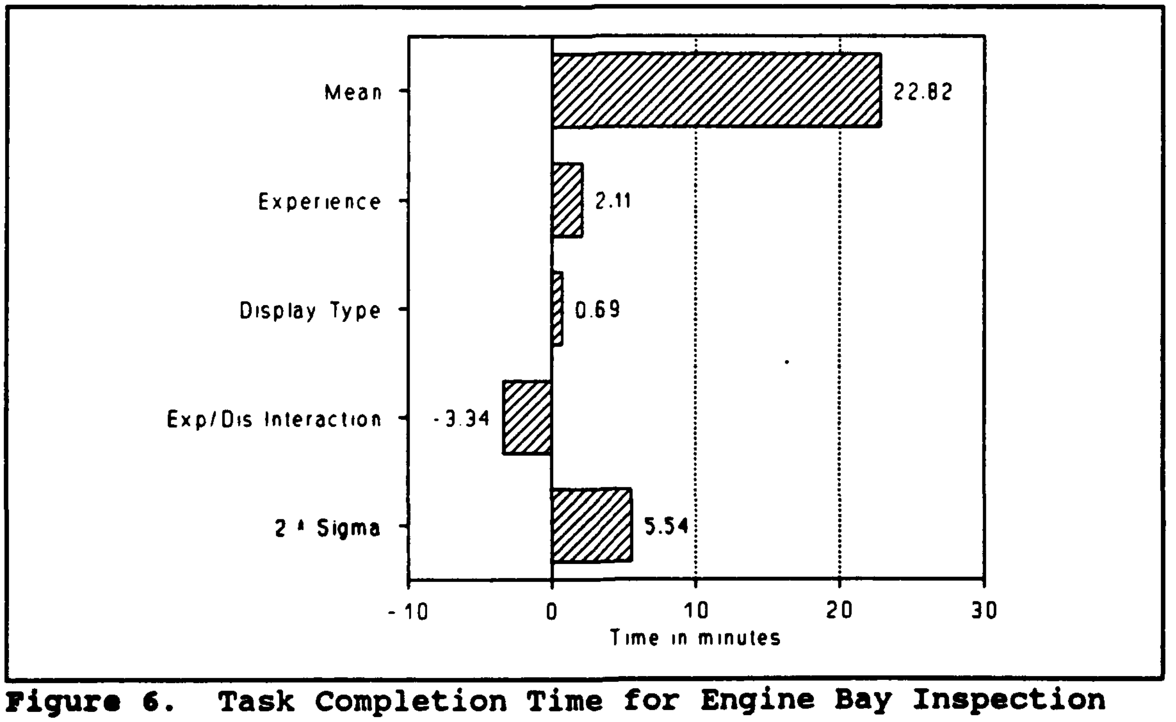

Figure 6. Task Completion Time for Engine Bay Inspection

Task Completion Times for the Total Sample

Figure 7 displays the results of the factorial analysis performed on the total sample of completion times. Unlike the previous factorial analysis, the total sample factorial used a 2^3 design. The analysis can be found in Chapter 3.

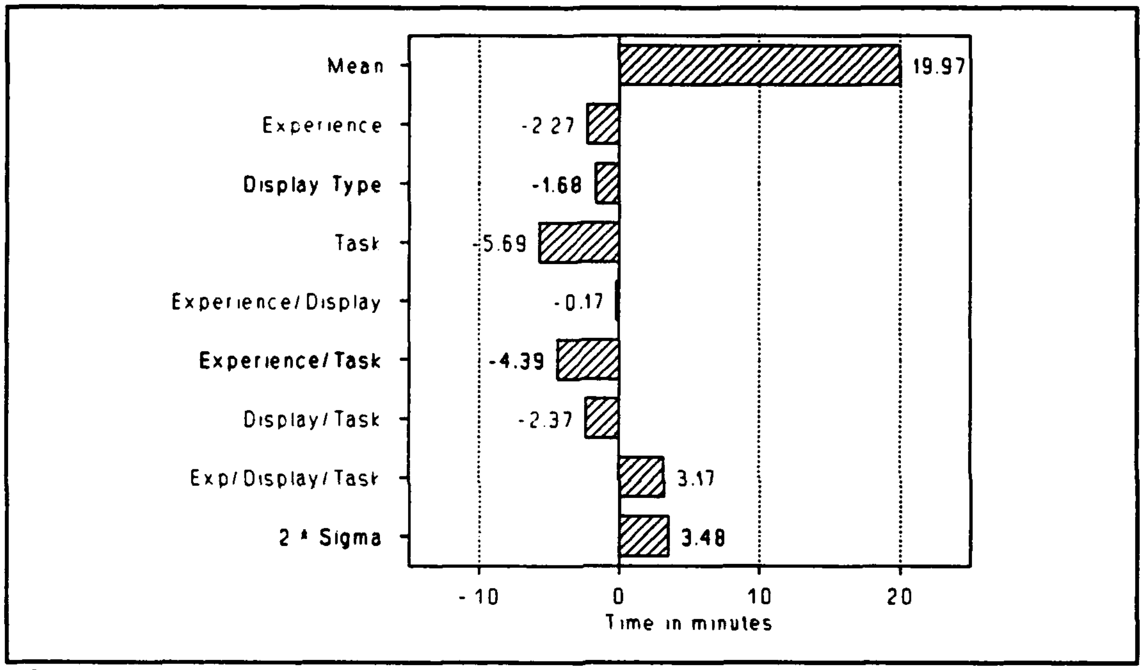

Figure 7. Task Completion Time for Total Sample

Three main effects and four interaction effects were evaluated based on all 29 trials conducted during the experiment. The task main effect and the experience/task interaction were the only effects that met the significance benchmark.

Task Main Effect. The task main effect confirms that the Engine Bay Inspection task took less time to complete than the Fault Isolation Test.

Experience/Task Interaction. The experience/task interaction effect provides an indication of how the task performed can influence the effect experience has on a technician's performance. Shown in Figure 8 is a graphical representation of this influence on technician performance.

Less-experienced technicians performing the Engine Bay Inspection completed the task 2.11 (23.88 - 21.77) minutes faster than the experienced technicians on average. The trend is reversed for the Fault Isolation test. Experienced

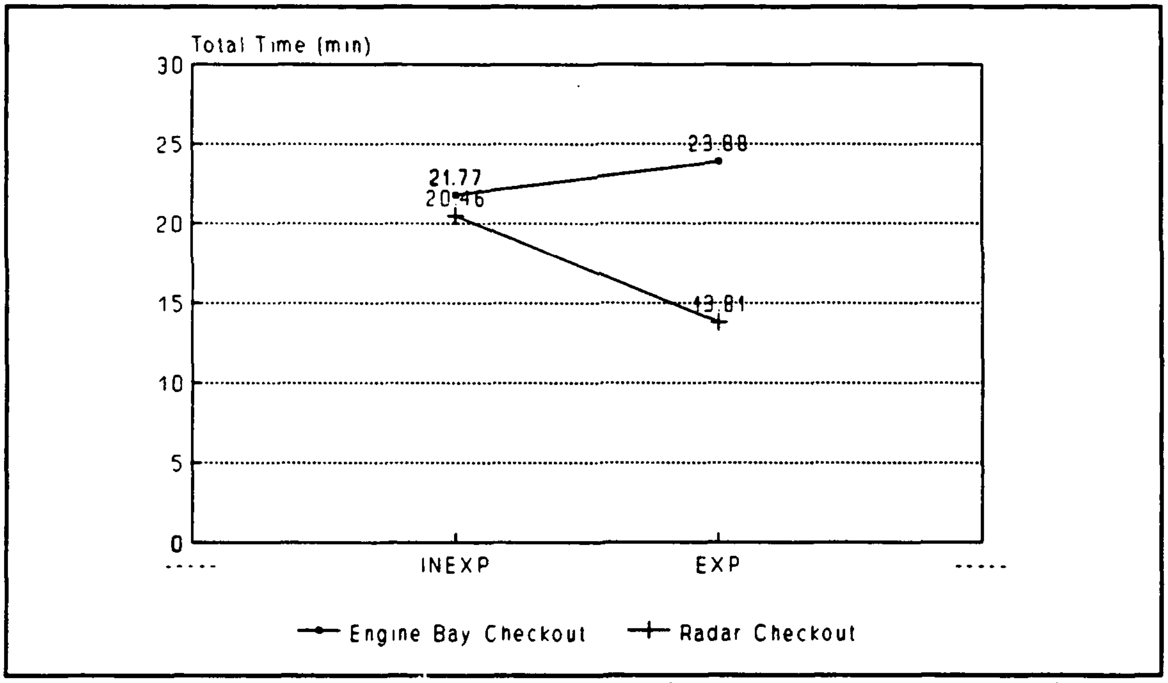

Figure 8. Experience/Task Interaction for Task Completion Time

technicians performed the task 6.65 (20.46 - 13.81) minutes faster on average than their less-experienced counterparts.

Number of Faults Found for the Engine Bay Inspection

The second measure used to evaluate technician performance was the number of faults found. The Engine Bay Inspection was unique because there were numerous faults in each of the subsystems inspected in the engine bay (in addition to the inserted fault). The associated 2^2 factorial analysis located in Appendix M was based on 16 trials. The results, shown in Figure 9, indicate that on the average, technicians found eight faults. The display type main effect appeared to significantly influence technician performance. The experience/display type interaction effect was slightly less than the 2σ benchmark but warrants discussion.

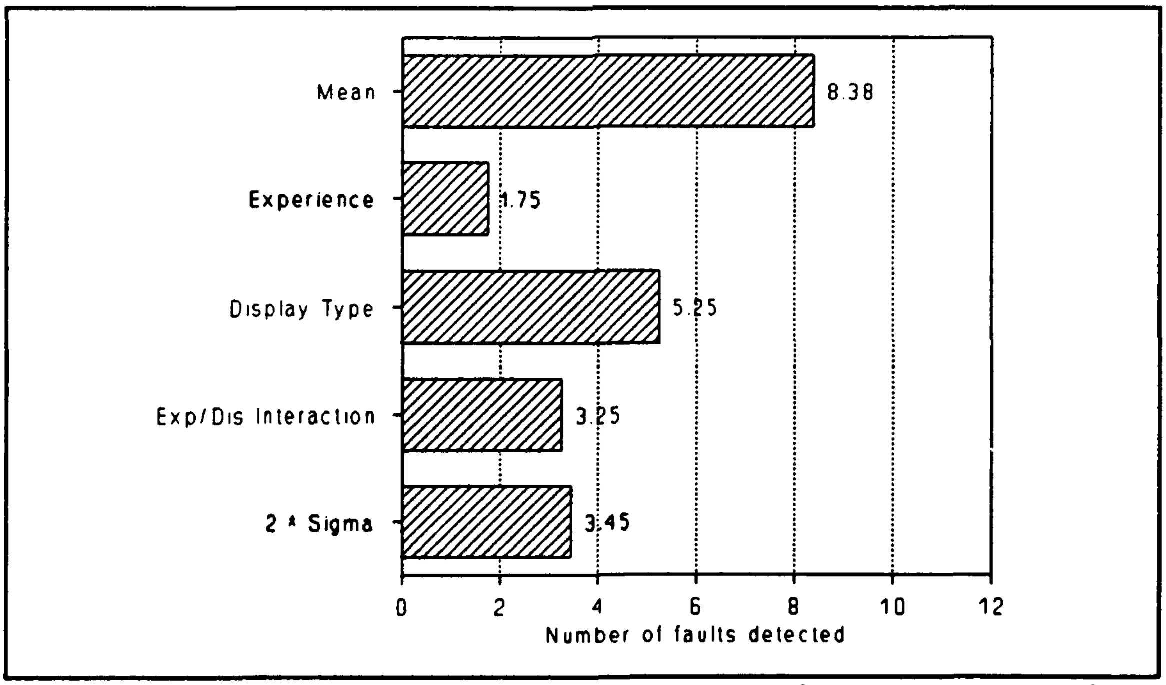

Figure 9. Number of Faults Found for Engine Bay Inspection

Display Main Effect. The display type effect favors the use of the HMDD over the PMA for finding more faults in an inspection task. Technicians using the HMDD tended to find five more faults on average than their PMA equipped counterparts.

Experience/Display Interaction Effect. In the previous discussion about the experience/display interaction for the Fault Isolation Test completion times, the findings suggested that less-experienced technicians benefitted the most from using the HMDD. However, with respect to the number of faults found, the findings suggest that experienced technicians benefitted more from the use of the HMDD than did the less-experienced. The graphical representation of this effect is shown in Figure 10. The

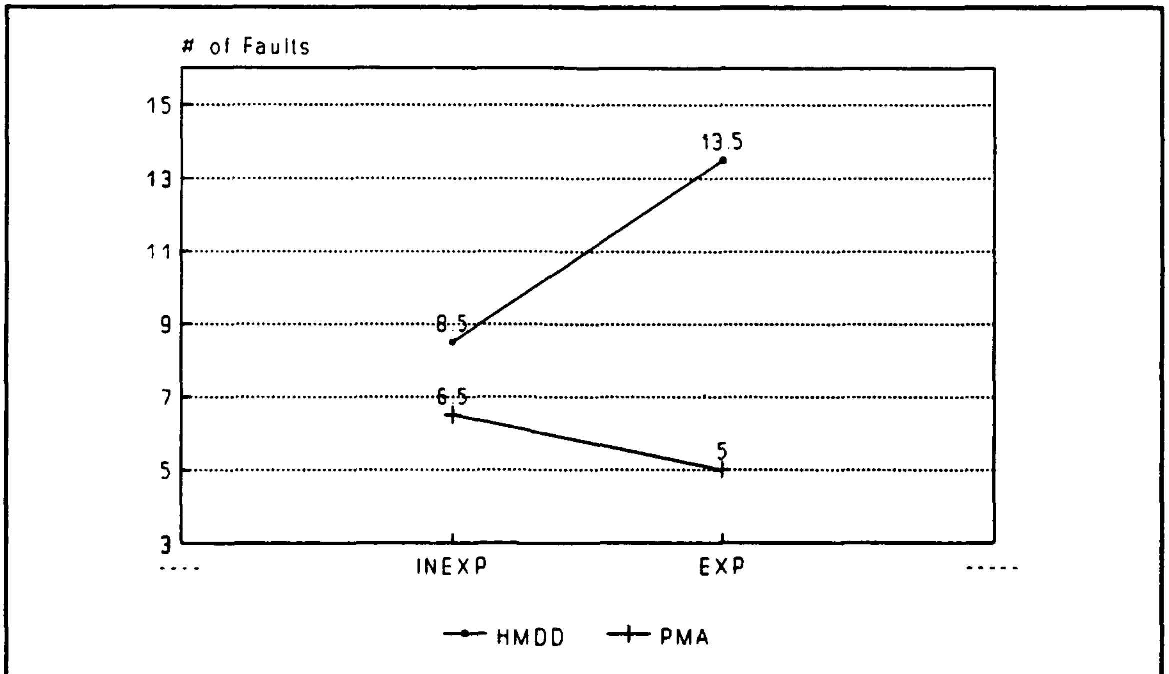

Figure 10. Experience/Display Interaction Effect for Engine Bay Inspection Faults Found

difference in the number of faults found by the experienced technicians was 8.5 (13.5 - 5). The difference in the number of faults found by the less-experienced technicians was two (8.5 - 6.5). Note that the number of possible faults remained constant throughout the experiment. Each technician had the same opportunity to find faults as the next.

Detection of Inserted Faults for Both Tasks

Each of the tasks had one inserted fault. In Appendix J, the Missed Detection of Inserted Faults Table shows the total number of technicians who missed the inserted faults. Shown in Table 5 below is the breakout of missed inserted

Table 5
Breakout of Missed Inserted Faults

Group	Missed/Total	Percentage
All Subjects	8/29	28%
HMDD	3/14	21%
PMA	5/15	33%
Experienced	3/15	20%
Less-Experienced	5/14	36%
Fault Isolation Test	4/13	31%
Engine Bay Inspection	4/16	25%

faults by factors. When considering display devices, 12% more of the technicians using the HMDD found the inserted fault than the technicians using the PMA. When considering experience level, 16% more of the experienced technicians found the inserted fault than the less-experienced technicians. When considering task type, the Engine Bay Inspection fault was found 6% more often than the fault in Fault Isolation Test.

Faults and Completion Times Interaction

Factors that improve technician effectiveness are often expected to improve efficiency as well. This relation was not the case, however, for the Engine Bay Inspection task. The relation of the measure used for effectiveness (total number of faults found and number of technicians that missed the inserted fault) to the measure used for efficiency (completion time for the technician to complete the task once regardless if the fault was found) was in most cases dichotomous. As previously discussed, the technician using the HMDD displayed more effective performance than the PMA equipped technician by finding more faults in the engine bay. With respect to experience level, the experienced technician performed more effectively (found more faults) than the less-experienced technician. However, the efficiency of these groups was reversed. Completion times for the Engine Bay Inspection suggested that HMDD equipped technicians were less efficient (took longer to perform the inspection) than the PMA equipped technicians. The experienced technicians were likewise less efficient than the less-experienced technicians in performing the inspection.

Completion time differences that were calculated using data presented in Table I bear this out. Technicians using the HMDD, on the average, took more than 1.38 minutes [(22.55+23.78)-(25.2+19.75)] longer to complete the inspection task than PMA-equipped technicians. Experienced technicians took 4.22 minutes [(22.55+25.20)-(23.78+19.75)] longer on the average than the less-experienced technicians in completing the Engine Bay Inspection task.

Survey and Interview Findings

The discussion in this section is divided into three areas: display device preferences, HMDD visual aspects, and screen fading. A complete listing of the questionnaire responses are contained in Appendix N. Appendix O and Appendix P contain the interview responses from the technicians who used the PMA and HMDD respectively.

Display Device Preferences. As discussed in Chapter 3, each technician performed one task using either the HMDD or the PMA. As a result, no technician could directly compare the display devices. Rather, the information displayed in Figure 11 is a compilation of each technician's subjective assessment of the device they used to perform the trial. The values shown are the mean values of the questionnaire responses obtained from the total sample of technicians who used either the HMDD or the PMA. The HMDD was evaluated by

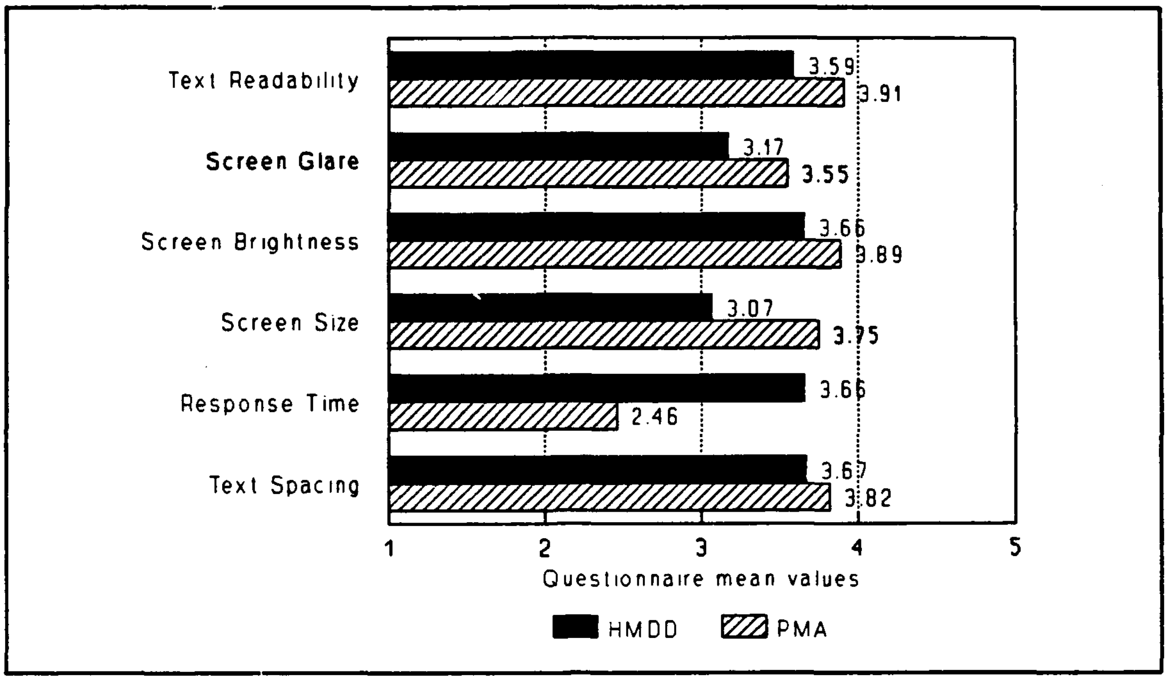

Figure 11. Technicians Questionnaire Responses

16 technicians, and the PMA was evaluated by 15. Means were used here to condense technician responses to provide the reader with an overall view of test subject perceptions. Appendix Q contains histograms portraying the full range of responses on each feature investigated. The rating values were based on the questionnaire's ordinal scale assignments. A 5 represented outstanding, 4 highly satisfactory, 3 satisfactory, 2 marginal, and 1 unsatisfactory.

Both display devices were generally rated between satisfactory and highly satisfactory. PMA-equipped technicians tended to express more satisfaction with the display device than HMDD-equipped technicians. Screen Size was one area of interest in which technicians using the HMDD were noticeably less satisfied than the PMA-equipped technicians. The lack of satisfaction with screen size was attributed to the requirement to adjust the CRT location of the HMDD in order to read the entire screen. The only area rated marginal was the response time of the PMA. The researchers knew in advance that the PMA had a slower computer response time and adjusted the task completion times to remove any biases caused by differing computer processing times. The computer response time problem was inherent to the PMA used in this experiment only. The most recent PMAs have central processing units which provide screen retrieval times comparable to the HMDD.

Technicians were asked if there was anything they disliked about using the display devices. The majority of the responses addressed characteristics specific to the hardware used during the trials. Some responses were: The vest was too hot, the headset too bulky, or the display devices were too heavy. The vast majority of the technicians felt that both displays improved their capability to perform maintenance activities. However, there was one exception: a technician using the PMA said he didn't see any advantage to using a computer to perform inspections. Many of the technicians' comments are addressed in the Recommendations section of Chapter 5.

Visual Aspects of the HMDD. Past research suggested that performing highly mobile activities while wearing a HMDD system might result in visual difficulties. Problems with retinal rivalry, lack of depth perception, and spatial disorientation were expressed as concerns. In addressing these concerns, this section will provide a description of the type of movements performed by technicians in this study. Next, technician evaluations with regard to visual problems encountered are presented. Finally, the researchers' assessment of the visual problems is offered.

Unlike Masquelier's study, the technicians in this study were required to be highly mobile. The Engine Bay Inspection required more complex ambulatory movements than the Fault Isolation Test. All experimental trials began in an office located on the second floor of the aircraft maintenance hangar. There, technicians were aided in putting on the HMDD equipment and the unit was turned on. The technical data for the appropriate task was then selected. For the trial, technicians performing the Fault Isolation Test were required to walk down a flight of stairs and across the hangar floor to the aircraft used. During this time, the HMDD was operating and displaying technical data. The technician was then required to climb a maintenance stand equipped with vertical stairs and climb into the cockpit using the aircraft's built-in steps (see Figure 12). The trial began when the technician was seated in the cockpit. Several times during the trial, the technician was required to stand up in the cockpit and look over the canopy to view the movement of the radar antenna. Throughout the experiment, none of the technicians exhibited or expressed difficulty in performing these actions.

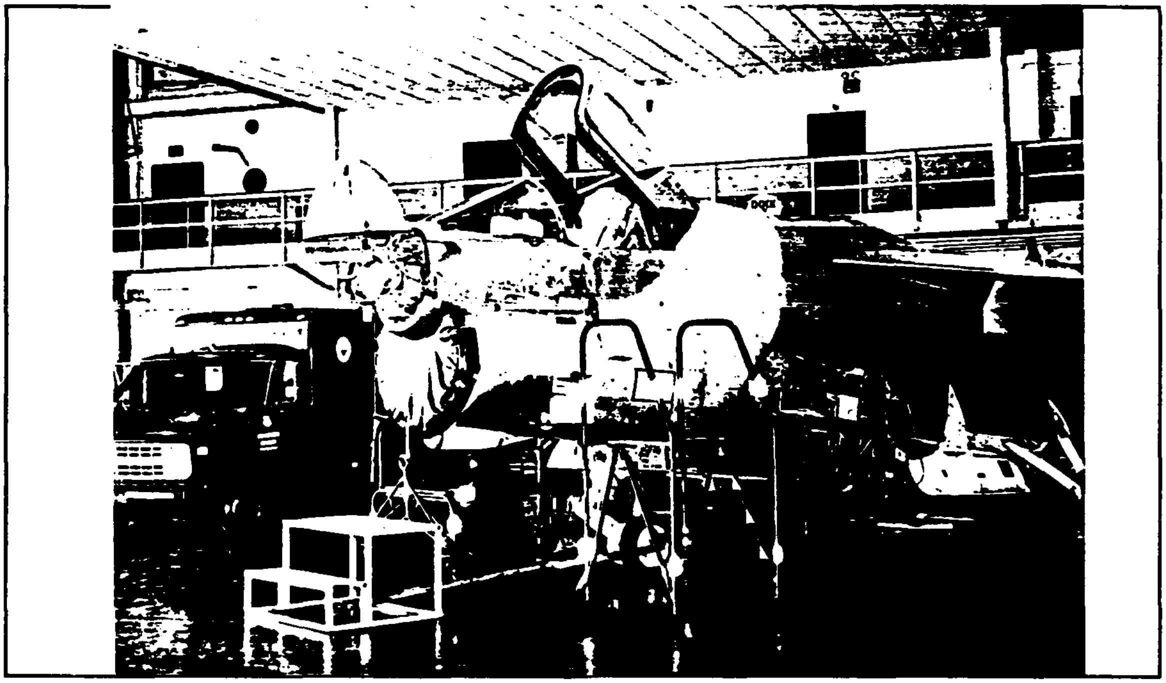

Figure 12. Fault Isolation Test Environment

Technicians performing the Engine Bay Inspection were required to go through the same initial sequence described above. However, the APG technicians were required to exit the hangar and walk approximately 50 yards across the aircraft parking ramp to the aircraft used for the trial. On most occasions, the ramp was brightly lit by sunlight. The trial began once the technician had arrived at the aircraft's aft end and had obtained a flashlight and mirror required for the inspection (see Figure 13). During the trial, the technician was required to enter and exit the engine bay numerous times. Each time, the technician was required to negotiate an approximate three-foot step up into the engine bay while avoiding the tail hook positioned directly aft of the aircraft. While inside the engine bay, the technician was required to stoop, twist, squat, lean,

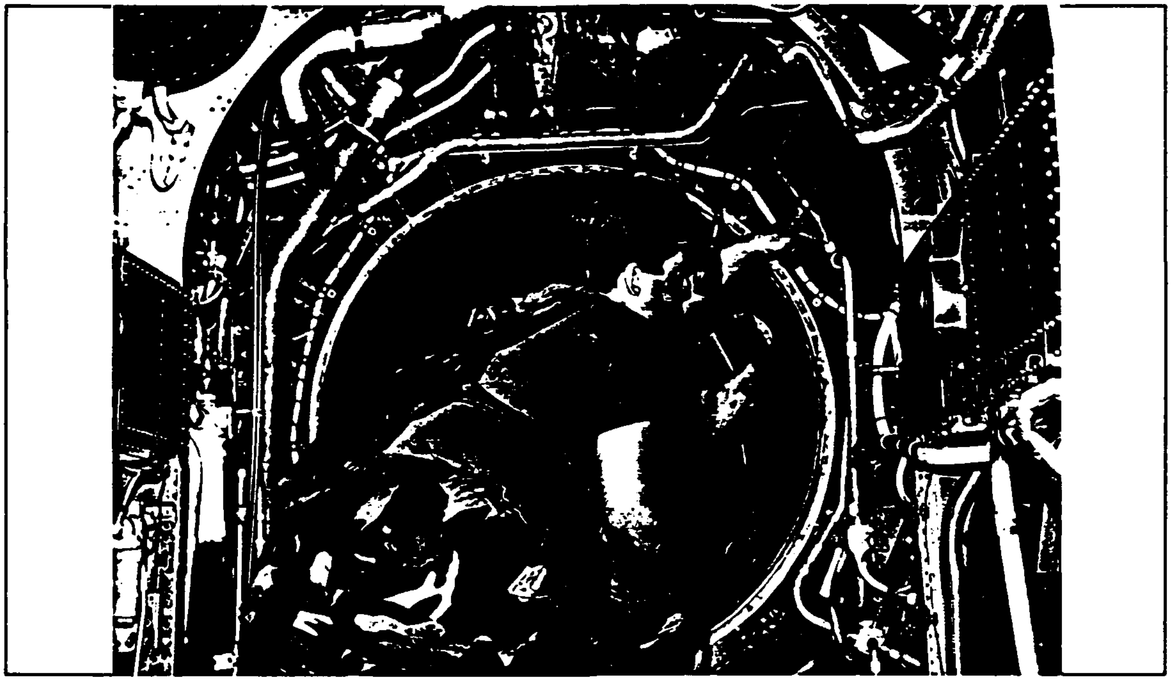

Figure 13. Technician Performing the Engine Bay Inspection

and stand. Throughout the inspection, the technician was required to balance himself on aircraft structural members to avoid damaging aircraft components underfoot (See Figure 14). None of the technicians stated that they had difficulty in performing these movements.

In the post-trial survey, technicians assessed six visual symptoms that could have resulted from using the HMDD. The symptoms were problems associated with (1) switching attention from the display to the surrounding environment and back, (2) eye strain, (3) blurring, (4) focusing, (5) afterimages, and (6) headaches. Figure 15 shows the technicians' responses to questions asked about the visual aspects of the HMDD.

On the average, all of the symptoms except eye strain were judged satisfactory. Some test subjects did experience

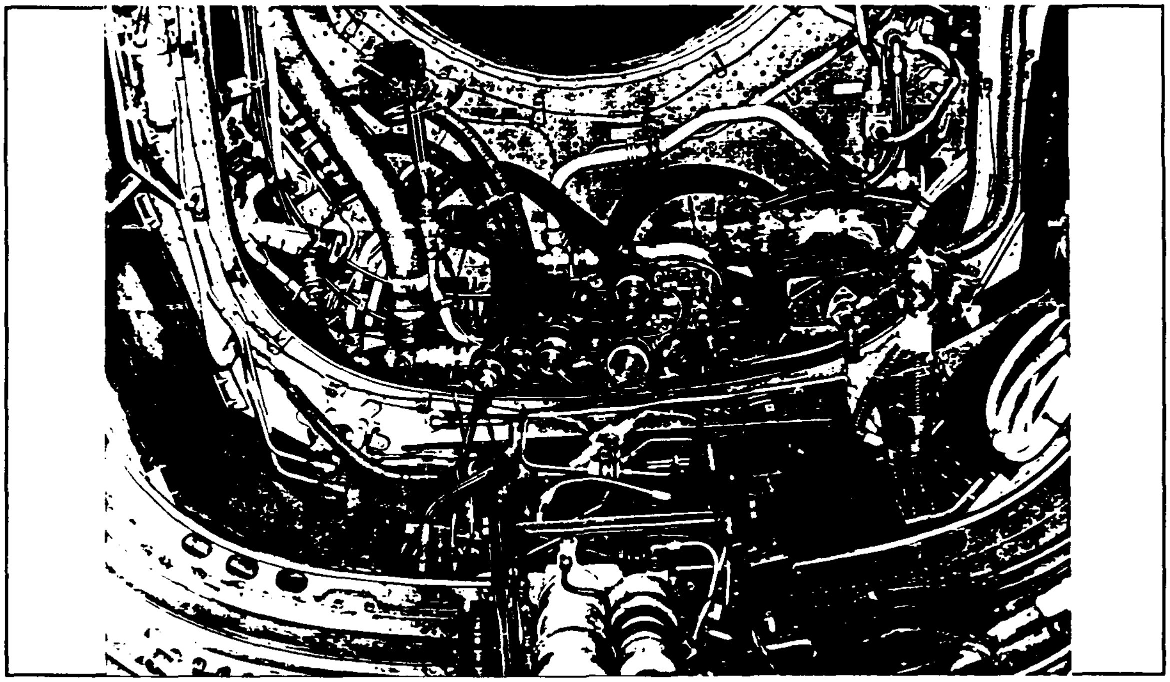

Figure 14. Engine Bay Floor Configuration

marginal results, however. Appendix N has the full range of responses provided by the technicians. A few technicians (six out of 16) speculated in the interviews that if the test had been longer, they would have experienced some eye strain. It would seem likely that this speculation was the result of some technicians experiencing the onset of eye fatigue as the result of viewing the HMDD. Although the survey responses regarding headaches appeared to be satisfactory, three less-experienced technicians using the HMDD reported getting headaches several hours after participating in the experiment. It is worth noting that the three technicians who experienced the headaches were the first technicians of the squadron to be tested using the HMDD. Researchers observed that technicians who were squinting at the beginning of the trial to view the HMDD screen were later able to view the screen with both eyes open. This behavior was confirmed in the post-trial interviews. Technicians stated that they found it easier to use the HMDD as they became more accustomed to it.

Survey responses, interview responses, and the researchers' observations suggest that technicians wearing the HMDD were able to operate physically complex actions

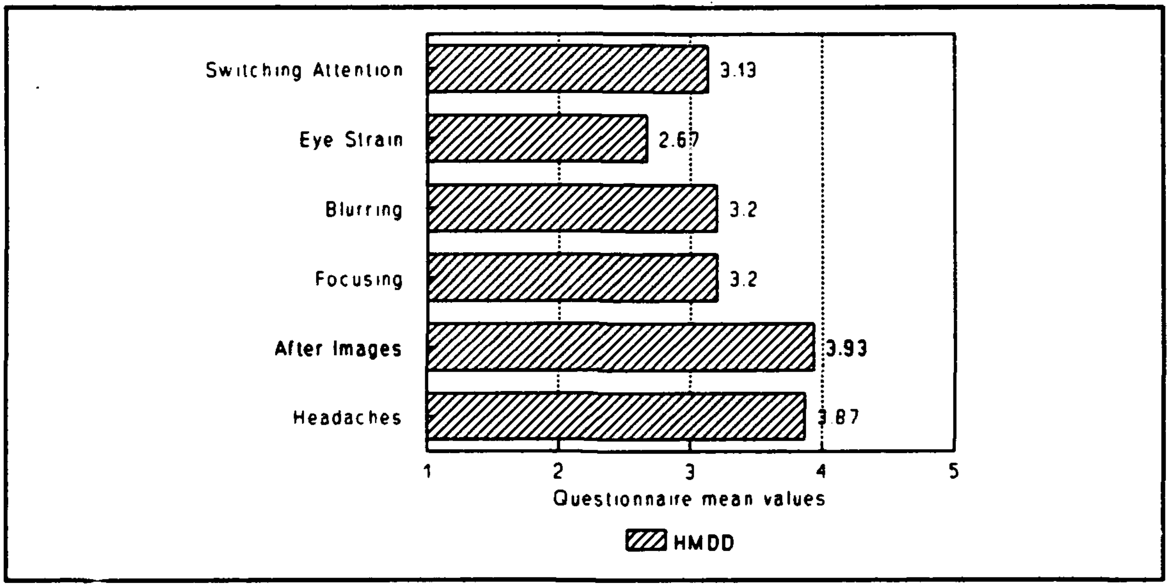

Figure 15. Visual Aspects of the HMDD

involving balance, eye-to-hand coordination, bending, twisting, and climbing under dim and bright lighting conditions without suffering adverse visual side effects (with the exception of the few technicians who experienced slight eye fatigue).

Screen Fading. Fading of electronic media display devices under bright sunlight conditions has been expressed as a concern in operating the HMDD in a flightline environment (see Chapter 2). Several areas of the base were evaluated to determine a location for comparing the two devices where they would be most susceptible to screen fading. Light meter readings and the corresponding Lux values obtained in various locations were recorded and are shown in Table 6.

Table 6
Various Location Lux Value Readings

Location	Meter Reading	Lux Value
QA Office	13	700
Aircraft Cockpit	12.5	525
Engine Bay	10.5	132
Flightline	19	44000

Based on these results, the HMDD and the PMA were observed under the same light conditions at the location where the light meter readings were the greatest: on the flightline clear of the surrounding buildings. The procedures used for testing was as follows.

The PMA was placed flat on the flightline. The PMA display was assessed based on the researcher's ability to stand three feet away and read the text displayed on the screen. The PMA was evaluated at different elevation angles through 360 degrees around the PMA. The researcher was able to read the text displayed on the PMA screen at all the viewing angles tested.

The HMDD system was evaluated at the same location. The HMDD screen was assessed by having a person wear the system and slowly turn while observing the text displayed. When the wearer turned to face the sunlight directly, the text was unreadable. The screen gradually became readable again as the wearer turned his head away from the direct sunlight. It appeared that the sunlight was reflecting off the wearer's face and washing out the text on the screen. When the same test was conducted with the wearer having untinted glasses, the fading was more pronounced.

In an attempt to reduce the problem, a tinted polarized lens from a 35MM camera was placed in front of the HMDD screen, and the test was repeated. The fading was significantly reduced. With the filter in place, the wearer could read the text while facing directly toward the sun. It is unclear whether the tinting or the polarization of the lens had the most effect in reducing the screen fading.

Synopsis

The purpose of this chapter was to inform the reader of the study findings. First, the actual conditions encountered during testing were defined to provide the reader with an understanding of the specific conduct of the study. A presentation of the detailed results followed for each of the primary measurements: completion times, detected faults, and user perceptions. The next chapter will provide the researchers' overall discussion of the findings.

V. Discussion of Findings

Overview

The purpose of this study was to determine if there were any additional benefits in using a monocular head-mounted display device rather than a hand-held flat-screen display device to present maintenance technical orders to technicians performing flightline tasks. By drawing on the findings of the previous chapter, this chapter will discuss the influence of the following factors on technician performance: (1) display type, (2) experience level, (3) type of task, (4) display type and task type interaction, (5) experience level and display type interaction, (6) experience level, display type, and task type interaction, and (7) participant perceptions of the HMDD and PMA. At the completion of these specific factor evaluations, a general assessment of the research question will be provided.

Display Type

The display type used to provide technical data made a measurable difference in technician performance during the experiment. For the Fault Isolation Test, technicians using the HMDD correctly identified the inserted fault more often and performed the task faster than technicians using the PMA. Furthermore, for the Engine Bay Inspection, HMDD-equipped technicians identified more discrepancies than PMA-equipped technicians.

In the opinion of the researchers, the improvement in technician performance was related to easy accessibility to technical data inherent in the HMDD. By having the data available within the technicians' field of view, they were more likely to read the information in smaller segments and at a higher sampling rate. In contrast, it was more difficult for a technician to obtain technical data displayed by a hand-held computer like the PMA while performing a maintenance activity. As a result, technicians equipped with the PMA were less likely to view the information as often as the HMDD-equipped technicians. Technicians who frequently view the data found it easier to determine what step they were on, when the step was completed, and what action was required next.

Experience Level

Technician experience level affected the performance measures as well. Experienced technicians correctly identified the faults more often than the less-experienced technicians. In the case of the Fault Isolation Test, the experienced technicians completed the tests faster than their less-experienced counterparts and exhibited a higher success rate in identifying the inserted fault. For the Engine Bay Inspection, the experienced technicians found more discrepancies and found the inserted discrepancy more often than their less-experienced counterparts. In the process, the experienced technicians took longer to complete the inspection than their less-experienced counterparts.

The researchers believe that experienced technicians were more familiar with the procedures examined. Therefore, the experienced technicians were able to comprehend the indicators provided to them during a maintenance activity to a fuller extent.

<u>Type of Task</u>

The type of task performed was a major factor in the performance measurements of this study. In reviewing the completion times, it was apparent that the two tasks required different amounts of time to perform the activities. The number of faults found also differed for each task. The very nature of the Fault Isolation Test limited the number of faults found to one. The Engine Bay Inspection, on the other hand, had over 20 possible faults that could have been identified. However, it is the task's influence on the relationship of the two performance measures that is significant.

<u>Task Influence on Performance Measures</u>

In the Fault Isolation Test, the two performance measures were found to be congruent. Technicians who performed the task quicker also found the inserted fault more often. However, as discussed in Chapter 4, in the section on the "Faults and Completion Times Interaction," the completion times and the number of faults found in the Engine Bay Inspection task provided diverging indications of technician performance. Shorter completion times were in conflict with the number of faults found. In general, the technicians who found the greater number of faults were the same technicians who took longer to complete the task. In the case of the Engine Bay Inspection, a longer completion time was an indication of more thorough visual inspection and improved performance. This would substantiate the need for two separate types of measures (in other words, both efficiency and effectiveness) in evaluating technician performance.

Experience/Task Interaction

In addition to the main effects, experimental results suggested that interaction effects influenced both performance measures. As mentioned in Chapter 3, "the main effect of a variable should be individually interpreted only if there is no evidence that the variable interacts with other variables" (Box, 178:317). In evaluating the task completion times, the experience/task interaction effect was found significant. When performing the Fault Isolation Test, experienced technicians completed the task faster than the less-experienced technicians on average. Conversely, for the Engine Bay Inspection task the trend was reversed. The less-experienced technicians took less time performing the task than did the experienced technicians on average. Thus, it would be inappropriate to focus solely on the effect of experience without also taking into consideration the type of task being performed.

Experience/Display/Task Interaction

The experience/display interaction affected the Fault Isolation Test's completion times differently than the Engine Bay Inspection's number of faults found. This dependence on the task is referred to as a three-factor interaction.

For the Fault Isolation Test, less-experienced technicians' completion times showed more improvement with the use of the HMDD than for the experienced technicians. It is the researchers' assessment that the nature of the Fault Isolation Test restricted the experienced technicians' range of improvement. A possible explanation of the task's influence on this interaction effect is that the Fault Isolation Test was a step-by-step procedure that required precise actions to be performed. Better performance in this task was indicated by shorter completion times and correct identification of the inserted fault. Since experienced technicians tend to operate the aircraft's systems quicker regardless of the display device used, there was little room for improving their performance by using the HMDD. Therefore, the possible range of performance improvement by an experienced technician was smaller than for the less-experienced technician.

For the Engine Bay Inspection task, the HMDD enhanced the experienced technicians' performance more so than the less-experienced technicians' performance. The Engine Bay Inspection was a more broadly defined task. The technical instructions for this task advised technicians to inspect specific areas and to look for certain conditions. From these conditions, the technician was required to assess the equipment's air worthiness. In contrast to the Fault Isolation Test, the experienced technicians' range of performance improvement was greater. In addition to having a greater range of performance improvement, the Engine Bay Inspection task appeared to provide the experienced technicians an advantage. Because the technician using the HMDD reads the information more frequently and in smaller sections, he or she receives more cues or flags as to what to look for. The increased frequency of cues combined with an experienced technician's larger knowledge base resulted in the experienced HMDD-equipped technicians finding the most faults as a group.

Participants' Perceptions

Technicians considered both the HMDD and the PMA as suitable displays for flightline maintenance. The technicians who used the PMA generally rated its performance higher in satisfaction than technicians using the HMDD, with the only exception relating to computer response time. The PMA used in this experiment had screen retrieval times much slower than the HMDD. AL had a PMA with essentially equivalent screen retrieval times, but it was not available for use in this experiment. When asked what they disliked about the devices, the majority of the participants responded with recommendations to improve system hardware or software. The majority felt that each device would benefit technician performance.

When asked about visual symptoms associated with the use of the HMDD in a dynamic environment, some of the technicians seemed to experience a slight degree of eye strain. The eye strain appeared to result from an unfamiliarity with switching attention from the HMDD to the surrounding environment and back. In the interview responses, several technicians indicated that it took a little practice to become accustomed to using the HMDD. While technicians tended to squint more during the initial part of the tasks performed, most technicians were viewing the HMDD without squinting by the end of the trial.

The researchers assessed the conditions associated with the HMDD tendency to experience screen fade in bright light conditions. They found that the HMDD screen was unreadable when the wearer faced directly into the sun. The problem appeared to be the sunlight's reflection on the wearer's face. A polarized tinted filter, placed in front of the screen, reduced the reflection enough so that the wearer could read the screen.

Summary

The purpose of this study was to determine if there were any additional benefits in using a monocular head-mounted display device as opposed to a hand-held flat-screen display device to present maintenance technical orders to technicians performing flightline tasks. By using the HMDD, technicians were provided easy access to technical instructions during the performance of a flightline maintenance activity. The results indicate that technicians performing tasks with data displayed on the HMDD generally performed better than their PMA-equipped counterparts. Experience was also an influencing factor. HMDD-equipped experienced technicians performing the Engine Bay Inspection were able to locate more discrepancies than any other group of technicians. The test data appears to favor the HMDD over the PMA. The degree to which these test results apply to other systems and circumstances remains to be seen.

The next chapter addresses the value of these findings with respect to the research question. In addition, insights on some possible improvements to the display devices and potential areas for further research are provided.

VI. Conclusions and Recommendations

Overview

After reviewing the experimental results and the discussions of the factors found to be influencing the experimental measures, it is appropriate to examine them in light of the overall research question. This chapter will investigate this question and will discuss some possible improvements to the display devices used and some areas that could benefit from further research.

Conclusions

Depending on the task and the performance measure considered, the display type significantly affects the performance of technicians performing flightline maintenance activities. For the Fault Isolation Test, technicians completed the task faster with the HMDD than with the PMA. For the Engine Bay Inspection, technicians found more discrepancies using the HMDD than with the PMA.

Experience level also had a significant effect on the technician's performance of flightline maintenance activities, again depending on the task and performance measure considered. For the Fault Isolation Test, experienced technicians performed the task faster and exhibited a higher success rate in identifying the inserted fault. For the Engine Bay Inspection, experienced technicians using the HMDD outperformed all other groups tested by finding more faults. These findings are congruent with Masquelier's results which found experience level to be significant. Future studies in this area might consider blocking on experience level in their initial design.

Armed with these experimental findings, the researchers are confident that the Air Force should consider employing HMDD systems for displaying technical data in a flightline maintenance environment. This study has shown that there are some tasks, specifically complex procedural tasks and inspection tasks, that may benefit from use of an HMDD. However, the use of an HMDD cannot be considered suitable for every maintenance action performed on a flightline.

As in most studies, the information presented here comes with some general caveats. Tests conducted at a national guard unit may have some associated biases that limit generalization to active duty units. Due to the exploratory nature of this study, time restrictions, and equipment and technician pool limitations, the data collected represents a small cross-section of the type of tasks, equipment, and organizations that could be evaluated.

Recommendations

One of the added benefits of exploratory research is that deficiencies can be identified early in the systems development. The HMDD and PMA units used during the experiment were one-of-a-kind prototypes. Use by several operational technicians in a realistic maintenance environment provided an early opportunity to suggest possible improvements to the systems. This section is divided into four separate areas for discussion: possible improvements to HMDD system, possible improvements to the PMA system, possible improvements common to the HMDD and PMA, and recommendations for follow-up experimentation.

Possible Improvements to the HMDD. Adjustment of the headset, which was necessary to view the entire screen, was a problem for several technicians. Difficulties were encountered when first putting on the ensemble and then positioning the eyepiece (or CRT) to where the technician could view the entire screen. Primarily, the weight of the screen and cable seem to cause the problem. Some technicians commented: "It tended to slip a bit when I tilted my head back," and "It seemed that the headset would start to fall off when I looked up." To fit the headband, the technician first positioned the eyepiece to where he could see the entire screen of text. Then, a locking knob on the side of the headset was tightened to secure the eyepiece's position in front of the technicians' eye. However, as soon as the technician removed his hand from the eyepiece, it would fall approximately one quarter inch (see Figure 16). Because the headset lacked a method of making minor adjustments, the best way to fine-tune the position of the eyepiece was by adjusting the position of the entire headband. Attempts to reposition the CRT and resecure the

Figure 16. Adjusting the HMDD's CRT

locking knob did not work as well. A method of making minor adjustments would be preferred over the all-or-nothing method provided by the locking knob. A possible solution could be a threaded arrangement that would allow the wearer to incrementally change the elevation and azimuth of the CRT.

The CRT also moved during both tests. The technician would have to stop and adjust the position of the headband to bring the entire screen back into viewing position. Unfortunately, wearing the headband tighter did not solve the problem. One comment was: "when I got it tight enough that it would not move, it became uncomfortable to wear after awhile." More effective methods of securing the eyepiece in position should be investigated.

The subject of screen fading was discussed at length in the Screen Fading section of chapter 4. The results of that investigation suggested that placing a tinted polarized filter on the front of the screen may alleviate most of the wearer's problems with operating the HMDD in bright lighting conditions.

The HMDD system generally received favorable comments. However, at least three technicians performing the Fault Isolation Test commented on the discomfort caused by the components in the back of the vest. Some technicians commented: "The battery pack and stuff on the back got in the way" and "Equipment on the back is uncomfortable." Equipment is also located on the front of the vest, and in certain bending and twisting motions, the equipment might become uncomfortable. Repositioning of the components, miniaturization, and padding are all possible solutions to this problem. The most common complaint about the vest was heat buildup from physical exertion while performing the experiments and functioning of the electronic components. One suggestion was to make the vest out of mesh material.

Possible Improvements to the PMA. Negative comments on the PMA focused on its bulk, weight, and screen durability. With the advances seen in portable computers, improvements in these areas should be possible. One technician recommended that a stand be incorporated into the system so the user could tilt the display. A stand could reduce glare on the screen and make it possible for a technician performing a task to read the screen without having to stand over the PMA. A possible solution to technician concern over damaging the screen would be to mount a plexiglass shield on it. The shield would have to be replaced after its translucency dulls; however, the cost would be less than replacing the screen.

Possible Improvements Common to the HMDD and the PMA. Batteries continue to be a hinderance to the use of portable electronic display devices. Although the PMA battery had a longer life than the HMDD, both systems required frequent recharging. Several technicians voiced concern over the reliability of these systems to display information when needed. Thus, both systems could benefit from a power management mode that would pause the system and power down the display. Reactivation of the screen would have to be easily and rapidly performed to avoid hindering the technician. Several times during testing, the display devices had to be powered down due to insufficient battery life or system lockup. In each case, the technical data had to be cycled through screen by screen, to the point where the system powered down. If the trial's procedures had been lengthier, returning to a point where the technician could have resumed would have required a significant amount of effort. Moreover, if such a power down were to occur on a complex maintenance activity, there would be increased risk that the technician may not return to the correct place in the technical instructions. Therefore, it would also be beneficial to have an electronic bookmark that allows the technician to return to the last screen viewed before system shutdown.

Further Experimentation. It is the researchers' opinion that further work is warranted. Past research has dealt with the use of the HMDD in a very dynamic (flying) environment and in a shop bench-level repair environment (Chapter 2). The current research focused on exploring the effect of display devices on two aircraft maintenance activities in a flightline environment. Additional maintenance tasks should be evaluated using the two display devices. Testing should include activities requiring more than one technician, activities requiring in-depth trouble-shooting analysis, activities requiring fast response turnaround, and activities requiring schematics. One technician said: "Schematics would be useful for chasing down wires during troubleshooting. It would be easier than the fold out charts the T.O.s have."

Further testing should consider using a more complex testbed. The A-7D electronics equipment does not have the complexity of a more modern aircraft, such as an F-15 or F-16. It may be the case that the display device effect on the technicians' performance would be more pronounced on a more complex test bed. As stated by one of the technicians: "The maintenance tasks involved in those aircraft would require a larger amount of data in different T.O. volumes."

There is also the human factors issue of HMDD suitability in an Nuclear-Biological-Chemical environment. Some technicians stated that performing maintenance activities while wearing chemical gear might be a problem. For instance, the eye-piece (as currently designed) would have to be worn outside the suit's plexiglass faceshield, which would affect the technician's ability to view the display and accomplish necessary maintenance tasks. Therefore, the compatibility of the HMDD with protective clothing warrants further study.

Two factors should be considered in developing any future experiment's strategy: (1) use of more than one performance measure, and (2) the use of factorial design (as opposed to the one-variable-at-a-time method). This study found that due to the complexity of technician performance, one measure could provide misleading results. Two or more measures provide a more complete picture of the behavior being studied. Factorial analysis is an effective tool in evaluating human-machine interactions, since it provides the ability to analytically evaluate the complex interrelationships likely to be encountered.

Appendix A: HMDD and PMA Hardware

HMDD Ensemble Hardware

The VGA HMDD used in the current research was manufactured by Imaging & Sensing Technology. It used a miniature CRT with a display format of 640 x 480 pixels on a monochrome (b/w) screen. The CRT had a picture size of 6mm x 8mm, cylinder size of 20mm in diameter and 80mm long, and a weight of 50g. A focusing mechanism weighing 60g was attached to the bottom of the CRT case. This assembly, including the attached video cable, was mounted on an adjustable surgeon's headband. The video cable connected the CRT to the drive electronics. Input supplied to the CRT from the drive electronics was at a vertical scan rate of 59-90 Hz non-interlaced, horizontal scan rate of 31.5 Hz, and the video was at 40 Hz analog. The drive components were mounted in a vest worn by the test subject. The power supply batteries were also contained in vest pockets. The two batteries were 12V, lead-acid, Quasar products. The computer drive was a 386 with 16MB of RAM and a 20MB flash drive. Power was connected with an on/off toggle switch located in an upper left front vest pocket. It was detented to prevent it from being inadvertently moved from one position to the other. The input devices used were two different types. The first was an aircraft type control stick. Two buttons were located on the top, one button retrieved the next screen of information, the other button retrieved the previous screen. The other input device was a telephone keypad arrangement with two buttons performing the same function as with the control stick. The configuration of the HMDD system is in Figures 17 and 18 shown below.

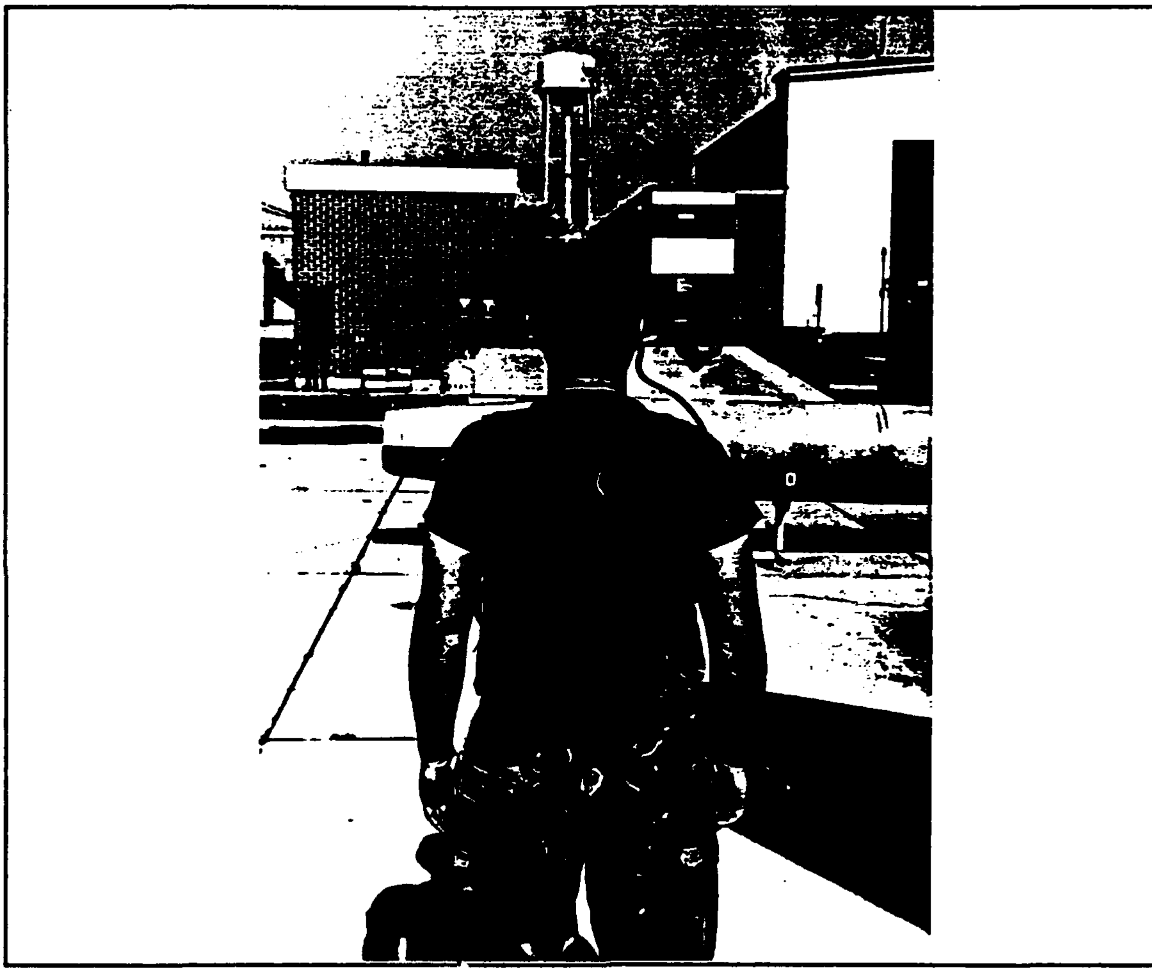

Figure 17. HMDD System Configuration (Back View)

<u>PMA Hardware</u>

The PMA used was assembled by AL. It used an Ovionics transflective LCD screen with a display format of 640 x480 pixels on a solid monochrome screen. Picture size was 6" x

Figure 18. HMDD System Configuration (Front View)

8". The drive electronics were from a Motorola 68020 based hybrid with 6MB of RAM and 4MB of flash memory. The graphics coprocessor was made by Intel. Power supply was from a 17V single silver cell battery pack (11 x 1.5). All the components, except for the battery, were enclosed in a carbon fiber case measuring 10.5" x 9.5" x 3.0". The entire assembly weighed approximately 7 pounds. Input to the computer was from a keyboard mounted on the top of the case. For the experiment, only two keys were needed. One key retrieved the next screen of text and one other key retrieved the previous screen. This arrangement was consistent for both the HMDD and the PMA. The PMA configuration is shown in Figure 19.

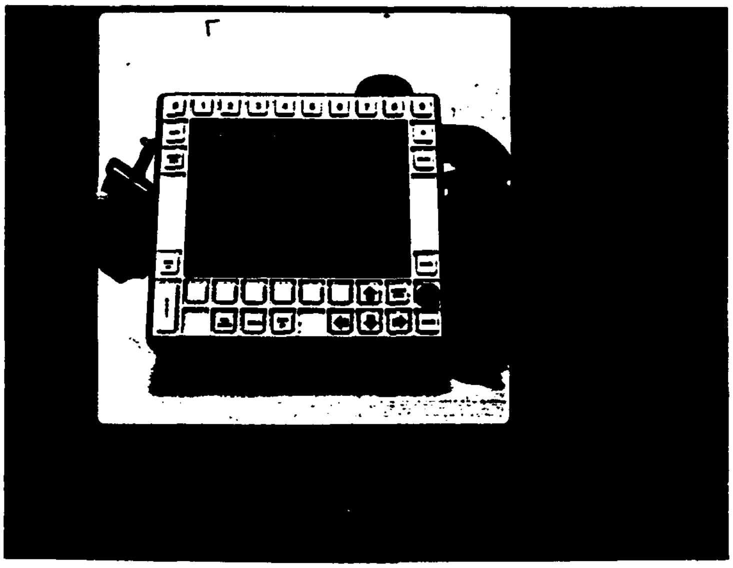

Figure 19. PMA System Configuration

Appendix B: User Evaluation Questionnaire

Please answer the following questions based on your participation in the evaluation. The questionnaire is divided into three sections with questions on visual aspects related to the use of each display, questions on the physical device, and questions on the information presented. Please read the questions carefully and put a circle around the appropriate response.

I. Questions on the Visual Aspects of the Displays

HMDD

1. Capability of switching your attention from the display to your work.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Eye Strain.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

3. Blurring.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

4. Focusing.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

5. Head Piece.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

6. Glare on the screen.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

7. Readability of all the information on the screen.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

8. After images.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

9. Green spots after using the HMDD.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

10. Headaches from using the HMDD.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

11. Contrast between the information displayed and the background.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

12. Brightness of the display.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

PMA

1. Glare on the screen.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Readability of all the information on the screen.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

3. Contrast between the information displayed and the background.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

4. Black text on the white background.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

5. Brightness of the display.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

II. Questions on the Physical Device.

HMDD

1. Focusing mechanism.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Control stick useability.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

3. Comfort of the vest and its contents.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

4. Capability of positioning the HMDD.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

5. Adequacy of screen size for displaying information.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

6. Computer response time.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

PMA

1. Keyboard.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Adequacy of the screen size for displaying information.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

3. Computer response time.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

III. Questions on the Information Presented.

HMDD

1. Readability of the text.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Spacing of information on the display screen (lack of clutter, etc.)

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

PMA

1. Readability of the text.

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

2. Spacing of information on the display screen (lack of clutter, etc.)

Outstanding	Highly Satisfactory	Satisfactory	Marginal	Unsatisfactory
A	B	C	D	E

Appendix C: Structured Interview

The following questions were asked of technicians using the PMA.

1. Is the information on the screen easy to read?

2. Can you give some examples of other activities that would be enhanced by using this device.

3. What did you not like about the device?

4. Were there any Visual problems with reading the screen (problems with glare)?

5. Was the task you performed representative of maintenance activities you are asked to routinely accomplish?

6. Looking at the manner in which we conducted the experiment, including the prebrief, instructions, eye examination, experiment, survey, and interview, would you like to see any changes made? Was the information adequate?

7. Do you have any other questions or comments?

The following questions were asked of the technicians using the HMDD.

1. Is the information on the screen easy to read?

2. Can you give some examples of other activities that would benefit from using this device?

3. What did you not like about the device?

4. Were there any Visual problems with reading the screen (problems with glare)?

5. Did you suffer any headaches or eye strain from using the device?

6. Did you have any problems with the headband?

7. Did you have any problem with the vest?

8. Was the task you performed representative of maintenance activities you are asked to routinely accomplish?

9. Looking at how we conducted the experiment, including the prebrief, instructions, eye examination, experiment, survey, and interview, would you like to see any changes made? Was

the information adequate?

10. Do you have any other questions or comments?

Appendix D: Personal Background

Subject ID ____

1. Check one: Full-Time Guardsman ____ Traditional Guardsman ____

2. Time in Service: ________ (yrs/mons)

3. Paygrade/Rank: _______

4. Current Specialty: (Job Title/AFSC) _________

5. Prior Work Experience:

	(1)	(2)	(3)
Work History	_________	________	________
Number of Years	_________	________	________

6. Education:

   Education (Highest Grade Completed) ___________

Appendix E: Engine Bay Inspection and Radar Fault Isolation Test Technical Data

Engine Bay Inspection Technical Data:

1. Fuel system.

A. All fuel and vent lines for dents, nicks, scratches, chafing, cracked B-nuts or sleeves, loose wiggins fitting, broken or improper size clamps (T.O. 1A-7D-2-6/1A-7K-2-6, T.O. 1-1A-8 and T.O. 44H3-1-3).

B. Hoses and tubing for collapsing, cracks, leakage, and insecurity (T.O. 1A-7D-2-6/1A-7K-2-6).

C. Motive flow disconnect coupling (215-53424-1, -3) for missing or broken aluminum locking dogs (T.O. 1A-7D-2-5/T.O. 1A-7K-2-5).

D. Fuel transfer selector valves (3) for corrosion and condition (T.O.1A-7D-2-6/T.O. 1A-7K-2-6).

2. UHT system.

A. UHT backup torque tube bolts (2) for broken lockwire.

B. Exposed areas of interconnect controlex for cleanliness (do not lubricate).

C. Controlex cable for binding in clamps, and proper size clamps. Disconnect controlex rod ends from bellcrank links. Disconnect bellcrank from right load-limiting link to provide access for spring scale. Determine force required to move the sliding part of controlex through full travel in both directions. Force should not exceed 4.0 pounds. Notify test conductors of results. Connect bellcrank to load limiting link. Connect controlex rod ends to bellcrank links.

D. Funk springs struts (2) for broken lockwire and insecurity of mounting.

E. Inspect left and right UHT backup connecting links (P/N 216-48101-2) for looseness and insecurity.

3. Fire detection system.

A. Sensing cable elements for insecurity of mounting, crimping, distortion, and corrosion.

4. Electrical system components and wiring.

A. All visible electrical wiring and connectors for fraying, chafing, loose or missing parts, fluid saturation, and serviceability.

B. Battery connectors for condition and corrosion.

5. The end

NOTE

THIS IS THE LAST SCREEN OF THE TEST. IF YOU SELECT BACKUP YOU CAN REVIEW THE ABOVE STEPS. IF YOU ARE FINISHED THEN SELECT NEXT.

****

Radar Fault Isolation Test:

1. The radar set is considered to be operating normally when proper responses as specified in the following procedures are obtained; however, a complete evaluation of the radar system operation requires additional testing. If a flight discrepancy cannot be duplicated during performance of the operational checkout, perform appropriate troubleshooting test or tests (paragraphs 4-46 and 4-69).

WARNING

Personnel and combustible materials must be kept out of microwave radiation hazardous area when radar is transmitting. Refer to maintenance precautions for hazardous distance information. To prevent possible serious injury or death to personnel, insure that requirements of T.O. 11A-1-33 are complied with before doing any of the following maintenance procedures.

CAUTION

When working on or near the antenna assembly, be careful not to damage antenna assembly components. Do not use waveguide sections or reflector assembly for handholds.

2. Connect external electrical power (paragraph 3-1).

3. Ensure RF absorbing curtain is in front of antenna.

4. Ensure weight-off-gear bypass switch is in NORMAL.

5. Ensure power switch on radar set control is in ON.

CAUTION

Before energizing radar set, ensure antenna boresight lockpins (elevation and azimuth) are disengaged to avoid damage to stabilization servos.

NOTE

As an alternate procedure, a MIL-T-26772 nitrogen service trailer may be used to maintain waveguide pressurization at 14.5 (+/- 0.5) psi.

NOTE

At facilities where field elevation is 4000 feet above sea level or higher a jumper plug may be temporarily installed on mount harness connector 2P5 to bypass the transmitter pressure switch. This jumper plug should be installed prior to applying power to radar set and should not be removed until after removing power from radar set.

NOTE

If the radar set automatically shuts down, overheating is indicated. If power supply-programmer or transmitter components repeatedly fail, the centrifugal fan should be checked for operation or damage, and fan screens should be checked for clogging.

NOTE

A number or numbers enclosed in parentheses at the end of a step in the following checkout is reference to a corresponding number in troubleshooting table 4-3.

6. Place radar set power switch in STBY. Antenna must slave to boresight in all axes and elevation and azimuth boresight lockpins must engage freely. (5 thru 8)

7. Place switches and controls as specified in table 4-1 (as shown below).

Table 4-1 Initial Control Settings.

Switch or Control	Position
Intratarget Data Indicator	
Brilliance	Fully Counterclockwise

Receiver gain	Fully Counterclockwise
Contrast	Fully Counterclockwise
Normal-Override	NORM
Cursor Control	Fully Counterclockwise
Normal-hold-expand	NORM
Autotilt	Deselected

8. Place switches and controls as specified in table 4-1 (as shown below).

Table 4-1 Initial Control Settings.

Switch or Control	Position
Radar Set Control	
Power	STBY
Antenna tilt	0(detent)
Frequency	4
Polarization	LIN
Mode	AGR

9. Place switches and controls as specified in table 4-1 (as shown below).

Table 4-1 Initial Control Settings.

Switch or Control	Position
Terrain Clearance & Range Set Control	
Terrain Clearance	2 X 100
Range Set	8.0
Antenna Scan Power Supply-Programmer	
Transmitter disable	NORM
Instrument Panel	
Master Function(switches)	Deselected(not green)
Heading mode	MAN HDG

10. Place switches and controls as specified in table 4-1 (as shown below).

Table 4-1 Initial Control Settings.

Switch or Control	Position
Tactical Computer	
Present Position Toggle	UPDATE
Computer power	OFF
Fault locator	
Fault locator selector	OFF

11. Rotate radar altimeter control fully clockwise from off (detent).

12. Place IMS mode select switch in GRID and tactical computer power switch in PWR.

13. Ensure radar set power switch is in STBY with 3-minute time in allowed. Press push-to-test light on fault locator. Safe light must come on. (9)

14. Place radar set control switch in PWR, select GMP, select 10-mile range, place radar set control switch in STBY, and then select AGR.

15. Place fault locator selector switch in BIT. Fault locator safe light must come on. (10) (Hit backup to review note.)

NOTE

> Indicator fail light will come on in all fault locator test positions. (This note applies to the last step on the screen.)

16. Place fault locator selector switch in ACFT. Safe light must come on. (11) Antenna should be slaved to 0 degrees in pitch, azimuth and roll. (Hit backup to review note.)

NOTE

> View antenna position from the cockpit. If the antenna is stationary assume it is slaved to 0 degrees in pitch, azimuth and roll. (This note applies to the last step on the screen.)

17. Place fault locator switch in P/S. Safe light shall blink once and must stay on. (12) Antenna should be scanning in CSTA. (Hit backup to review note.)

18. View the antenna from the cockpit. If the antenna is slewing, assume that is scanning in CSTA.

19. Place frequency selector in 1.

20. Place fault locator selector switch in XMTR. Safe light must come on. (13) (Waveguide switches energize, and antenna should be scanning in CSTA. Adjust brilliance and contrast control on indicator for desired display. Indicator display will flash on and off at the elevation scan rate.)

21. Place frequency control in frequency positions 5,3,6,2, in that order. At each frequency setting, cycle fault locator switch to P/S and then to XMTR and observe that safe light comes on in each position. (13)

22. Place fault locator selector switch in CMPTR. Safe light must come on. (15) Antenna should be scanning in CSTA and indicator must be blank.

23. Place fault locator select switch in A/R. Verify safe light comes on within 10 seconds, but not immediately. (16 & 17) (Antenna scans in CSTA until safe light comes on and

then is slaved to boresight. Indicator displays a flashing +/- 20 degrees PPI sweep at the elevation scan rate until antenna goes to boresight; then indicator is blank. Waveguide switches are energized until antenna goes to boresight, and then switches deenergize.)

24. Repeat previous step for frequency selector positions 4 and 7. Return fault locator selector switch to CMPTR prior to performing previous step for each frequency selected. Safe light must come on in each frequency selected. (17) (Hit backup to review note)

NOTE

> If the following test is run without a 10-second wait between steps, the safe light will return faster each time it is run. (Note applies to step 25)

25. Place fault locator selector switch in CMPTR 2. Safe light must come on. Fault locator safe light may be on intermittently. This condition is acceptable. (18) Antenna should be scanning in CSTA and indicator shall be blank.

26. Place fault locator selector switch in CMPTR 3. Safe light must come on. Antenna should be scanning in CSTA and indicator should blank. Fault locator safe light may be on intermittently. This condition is acceptable. (18)

27. Press range change/target reject switch on throttle quadrant until indicator 10 light comes on. Place fault locator switch in SW GEN. Antenna should be scanning +/- 45 degrees. Safe light must not come on.

28. Adjust brilliance and contrast control on indicator to obtain display with minimum flicker. Verify display is 128 light vertical lines separated by narrow dark lines with no discontinuities. (fig. 4-2A). (19, 19A, 19B)

29. Press range change/target reject switch on throttle quadrant one time. Observe the following:

A. Range must change from 10 to 5 miles. (42)

B. Indicator display must change to complement of former display (light lines become dark and narrow dark lines become light). (19 and 19A)

30. Press range change/target reject switch on throttle quadrant one time. Verify indicator displays +/- 45 degrees PPI scan (shades of grey) and fault locator (fig. 4-2A) safe light comes on. (19)

31. Press range change/target reject switch on throttle quadrant one time. Verify indicator displays memory test No. 3 (fig. 4-2A).

NOTE

Further action of range change/target reject switch cycles radar indicator displays between memory test No. 3 and BITE gray shades displays. (This note applies to the last step on the screen.)

32. Place frequency selector in 4 and fault locator selector switch in SCAN INTER. (Hit backup to review note.)

34. The end.

WARNING

THIS IS THE LAST SCREEN OF THE TEST. IF YOU SELECT BACKUP YOU CAN REVIEW THE ABOVE STEPS. IF YOU ARE FINISHED THEN SELECT NEXT.

Appendix F: Briefing Instructions

Introduction

Thank you for volunteering to be a test subject in the evaluation of two different electronic display devices for the presentation of maintenance technical information.

I am Captain Jeff Friend and this is Capt Randy Grinstead. We are graduate students at the Air Force Institute of Technology and we are performing this experiment as part of our thesis requirement.

Purpose

The purpose of this experiment is to compare the performance of technicians accomplishing maintenance tasks with technical data presented on a hand-held display system **(Point to the PMA computer)** and a head-mounted monocular display system **(Point to the HMDD)**.

This experiment is sponsored by the Armstrong Laboratory, located in Area B at Wright-Patterson AFB, as part a program called the Integrated Maintenance Information System or IMIS. IMIS is a developmental project aimed at providing technicians with a flight line computer to support maintenance activities. Some of these activities include providing technical data for specific aircraft, retrieving spare parts information from the supply computer, providing automated diagnostic routines, displaying historical information either from CAMS or the wing, and supporting training requirements. The information obtained from this experiment will support the selection of a display technology for future weapon systems such as the F-22.

<u>Experimental Description</u>

There are a total of 24 maintenance technicians participating in this experiment. Technicians have been divided into two groups, full-time guardsmen and traditional guardsmen. Each group is made up of personnel from the Avionics shop and the APG shop. Each technician will receive training on how to operate the two display devices. Then each person will perform one of two maintenance tasks tailored to meet the requirements of the experiment. Those tasks are a checkout of the APQ-126 radar and an inspection of the engine bay normally performed during phase inspection. Both tasks may or may not have faults or discrepancies inserted into the system being evaluated. You will be asked to perform a task using the portable hand-held display device or the head-mounted display device. Your job will be to perform the steps displayed and identify any faults or discrepancies you have encountered. We will be recording the amount of time between each fault detection and total task completion time. You are encouraged to work as quickly as possible. After you complete your experiment, you will be asked to complete a questionnaire which addresses certain aspects of the display devices and the information displayed. We also will be performing personal interviews with each participant to hear in your words how you feel about the various display devices. The information collected in this experiment will not be associated with your name. Participants will only be identified by subject number. The data collected will not be related to your job performance. Your supervisor will not know how you did on the experiment nor will he hear any of the comments you provide during the debriefing. The sequence of events will be as follows:

- Random assignment of subjects to experimental conditions.
- Introduction to the experiment.
- Eye examinations will be performed.
- Written operating instructions on the computer to be used will be provided.
- Hands-on computer training.
- Technician to perform experiment.
- Experimenters to debrief technician, administer the questionnaire, and perform a personnel interview.

Appendix G: Training Instructions

Using the Hand-held Display

You will be using a specially constructed hand held computer for displaying the steps you must perform during this experiment. This briefing will provide you with instructions on the basic operation of the computer before the test gets underway. Please feel free to ask any questions at any time if the instructions and procedures we describe are not clear.

The information contained in the hand-held computer was extracted from engine bay checkout workcards and the operational checkout of the APQ-126 radar system. Some modifications have been made to the procedures to facilitate this experiment. Three workcards from the engine bay checkout were selected and tailored, and a procedure from T.O. 1A-7D-2-8 was inserted into the checkout. All of the steps for the engine bay workout will be performed inside the engine bay compartment of the aircraft and the total time to complete the task should be around thirty minutes. The fault isolation test was extracted from the radar operational checkout maintenance activity. All of the steps will be conducted on the ground immediately beside the aircraft or in the aircraft's cockpit. This procedure should take approximately thirty minutes as well. Although the modified procedures have been greatly reduced, the wording for the steps selected are similar to what you would normally use to checkout the engine bay and APQ-126 radar.

The screen layout is a straight forward configuration. At the top of each screen you will see the "title bar", which tells you what task you are performing. At the bottom of the screen is the "menu line". Shown on the menu line are several blocks with keywords in each. For the purposes of this experiment these blocks can be ignored. Directly above the menu line is the "instruction line" which tells you what keystroke to perform next. In the remainder of the screen, between the "title bar" and "instruction line", is where technical information will be displayed.

When appropriate, NOTES, CAUTIONS, and WARNINGS will appear on the screen as separate text boxes overlaid over the steps for which the NOTE, CAUTION, or WARNING applies. On the lower left hand corner of these text boxes is a rectangular box containing the word OK highlighted by means of dark double lines. The double lines mean this box is defaulted to the NEXT command. In this experiment the command highlighted will always be the NEXT command. After hitting NEXT the NOTE, CAUTION, or WARNING will disappear. If at any time you wish to backup and review a NOTE, CAUTION, WARNING or any previous screen, the keystroke will be BACKUP. One final point about the NOTES, CAUTIONS, and WARNINGS. On each you might see a scroll bar. All of the NOTES, CAUTIONS, and WARNINGS for this experiment have been segmented so that all of the text is visible without the use of the scroll bar, ignore it.

When you receive the computer, it will be already activated and displaying the first steps of the experimental task. Once we instruct you to begin, you will go through each screen performing the technical instructions. Do only as the technical instructions state; DO NOT perform troubleshooting or attempt repair as you normally might. You have completed the performance portion of the experiment when you get to the screen containing the last technical instructions. To remind you that you are on the last screen containing technical instructions we have inserted a CAUTION. Read the CAUTION and then hit NEXT to complete the last screen of the technical instructions. Because we are recording completion times it is important that when you complete the last step you alert one of us that you have done so. Do not turn off the computer. Hand the computer to one of us at the completion of the task. Please do not discuss any of the discrepancies you may have found during the experiment. There will be 11 other members from your shop performing this experiment and the results will skewed if they know in advance the location of possible discrepancies.

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

Using the Head-Mounted Display System

You will be using the head-mounted display system as the source of checkout maintenance information for one of the tasks. This briefing will provide you with instructions on the basic operation of the computer before the test gets underway. Please feel free to ask any questions at any time if the instructions and procedures we describe are not clear.

The information contained in the head-mounted computer was extracted from engine bay checkout workcards and the operational checkout of the APQ-126 radar system. Some modifications have been made to the procedures to facilitate this experiment. Three workcards from the engine bay checkout were selected and tailored, and a procedure from T.O. 1A-7D-2-8 was inserted into the checkout. All of the steps for the engine bay workout will be performed inside the engine bay compartment of the aircraft and the total time to complete the task should be around thirty minutes. The fault isolation test was extracted from the radar operational checkout maintenance activity. All of the steps will be conducted on the ground immediately beside the aircraft or in the aircraft's cockpit. This procedure should take approximately thirty minutes as well. Although the modified procedures have been greatly reduced, the wording for the steps selected are similar to what you would normally use to checkout the engine bay and APQ-126 radar.

The screen layout is a straight forward configuration. At the top of each screen you will see the "title bar", which tells you what task you are performing. At the bottom of the screen is the "menu line". Shown on the menu line are several blocks with keywords in each. For the purposes of this experiment these blocks can be ignored. Directly above the menu line is the "instruction line" which tells you what keystroke to perform next. In the remainder of the screen, between the "title bar" and "instruction line", is where technical information will be displayed.

When appropriate, NOTES, CAUTIONS, and WARNINGS will appear on the screen as separate text boxes overlaid over the steps for which the NOTE, CAUTION, or WARNING applies. On the lower left hand corner of these text boxes is a rectangular box containing the word OK highlighted by means of dark double lines. The double lines mean this box is defaulted to the NEXT command. In this experiment the command highlighted will always be the NEXT command. To execute the NEXT command depress the (red) right top button on the pistol grip. After hitting NEXT the NOTE, CAUTION, or WARNING will disappear. If at any time you wish to backup and review a NOTE, CAUTION, WARNING or any previous screen, invoke the BACKUP command by depressing the (black) left top button of the pistol grip. One final point about the NOTES, CAUTIONS, and WARNINGS. On each you might see a scroll bar. All of the NOTES, CAUTIONS, and WARNINGS for this experiment have been segmented so that all of the text is visible without the use of the scroll bar, ignore it.

Using the HMDD system requires the user make some adjustments prior to beginning the experiment. The head band size is adjusted through the use of the knob on the back of the head band. The location of the eye piece through the knob on the side of the headset. To adjust the focus on the display device, use the small thumbwheel on the top of the eye piece. We will help you with the adjustments. The vest should also be fastened and adjusted so that the wearer is comfortable. When you receive the computer, it will be already activated and displaying the first steps of the experimental task. Once we instruct you to begin, you will go through each screen performing the technical instructions. Do only as the technical instructions state; DO NOT perform troubleshooting or attempt repair as you normally might. You have completed the performance portion of the experiment when you get to the screen containing the last technical instructions. To remind you that you are on the last screen containing technical instructions we have inserted a CAUTION. Read the CAUTION and then hit NEXT to complete the last screen of the technical instructions. Because we are recording completion times it is important that when you complete the last step you alert one of us that you have done so. Do not turn off the computer. We will help you with its removal. Please do not discuss any of the discrepancies you may have found during the experiment. There will be 11 other members from your shop performing this experiment and the results will skewed if they know in advance the location of possible discrepancies.

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

Appendix H: Debriefing Instructions

We are grateful for your participation in this evaluation. The purpose of the experiment was to compare the performance of technicians accomplishing maintenance tasks with technical data presented on a hand-held display and a monocular display device. The F-22 and B-2 are both going to have digital technical information for technicians on the flightline and in the shops. The information from this evaluation will support the selection of a display technology for future weapon systems.

The information received from user evaluations and personal interviews is central to this evaluation. The results of this study will be available to all federal agencies who wish to request a copy.

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

We will return to the wing in August with a briefing of the experimental results after data analysis has been performed.

Thanks again for your participation. We would appreciate your not discussing any aspect of this evaluation with your co-workers until all of the data has been collected.

Appendix I: Observation Form

Subject ID ______

1. Task ________________ HMDD _____ PMA _____

****

RADAR CHECKOUT
Start Time: _________________
Fault Find Time: ____________
Termination Time: ___________
No. of Keystrokes: N____ B____
Correct: _____ Abort: _____

ENGINE BAY CHECKOUT
Start Time: _________________
Fault Find Time: __________
Termination Time: ___________
No. of Keystrokes: N____ B____
Correct: _____ Abort: _____

COMMENTS/OBSERVATION:

Appendix J: Task Completion Times for the Overall Sample

Total Completion Times for Total Sample

1.	HMDD/EXP/TASK 1	16.73	15.	PMA/EXP/TASK 1	22.34
2.	HMDD/EXP/TASK 1	31.85	16.	PMA/EXP/TASK 1	22.19
3.	HMDD/EXP/TASK 1	22.05	17.	PMA/EXP/TASK 1	26.02
4.	HMDD/EXP/TASK 1	19.57	18.	PMA/EXP/TASK 1	30.26
5.	HMDD/EXP/TASK 2	12.08	19.	PMA/EXP/TASK 2	11.61
6.	HMDD/EXP/TASK 2	13.80	20.	PMA/EXP/TASK 2	16.01
7.	HMDD/EXP/TASK 2	13.95	21.	PMA/EXP/TASK 2	11.80
8.	HMDD/INEXP/TASK 1	21.82	22.	PMA/EXP/TASK 2	17.89
9.	HMDD/INEXP/TASK 1	31.77	23.	PMA/INEXP/TASK 1	14.39
10.	HMDD/INEXP/TASK 1	15.78	24.	PMA/INEXP/TASK 1	22.89
11.	HMDD/INEXP/TASK 1	25.73	25.	PMA/INEXP/TASK 1	17.76
12.	HMDD/INEXP/TASK 2	13.97	26.	PMA/INEXP/TASK 1	23.94
13.	HMDD/INEXP/TASK 2	19.80	27.	PMA/INEXP/TASK 2	23.10
14.	HMDD/INEXP/TASK 2	17.02	28.	PMA/INEXP/TASK 2	20.24
			29.	PMA/INEXP/TASK 2	28.62

(Time is recorded in minutes and fractions of a minute.)

****

Missed Detection of Inserted Faults

Engine Bay Checkout			Fault Isolation Test		
	HMDD	PMA		HMDD	PMA
EXP	1(4)	1(4)	EXP	0(3)	1(4)
INX	1(4)	1(4)	INX	1(3)	2(3)

( ) Indicates total number performing checkout.

Appendix K: Factorial Analysis Results for Task Completion Time for Radar Fault Isolation Test

Mean	Exp	Dis	Exp/Dis	Avg Obs
1	-1	-1	1	23.99
1	1	-1	-1	14.33
1	-1	1	-1	16.93
1	1	1	1	13.28
4	2	2	2	
17.13	-6.66	-4.06	3.00	

Pooled Estimate	10.29
Variance of Effect	2.57
Standard Error	1.60
2* Sigma	3.21

Appendix L: Factorial Analysis Results for Task Completion Time for Engine Bay Inspection

Mean	Exp	Dis	Exp/Dis	Avg Obs
1	-1	-1	1	19.75
1	1	-1	-1	25.20
1	-1	1	-1	23.78
1	1	1	1	22.55
4	2	2	2	
22.82	2.11	0.69	-3.34	

Pooled Estimate	30.72
Variance of Effect	7.68
Standard Error	2.77
2* Sigma	5.54

Appendix M: Factorial Analysis Results for Number of Engine Bay Inspection Faults Found

Mean	Exp	Dis	Exp/Dis	Avg Obs
1	-1	-1	1	6.5
1	1	-1	-1	5
1	-1	1	-1	8.5
1	1	1	1	13.5
4	2	2	2	
8.38	1.75	5.25	3.25	

Pooled Estimate	11.92
Variance of Effect	2.98
Standard Error	1.73
2* Sigma	3.45

Appendix N: Questionnaire Breakdown

The following is breakdown of each subject's responses to each question shown on Appendix B. The breakdown arrangement follows that of the questionnaire.

Section I

HMDD

	A	B	C	D	E
Question 1	2	2	7	4	0
Question 2	0	1	8	6	0
Question 3	1	5	6	3	0
Question 4	2	3	6	4	0
Question 5	0	0	4	9	2
Question 6	2	3	7	2	1
Question 7	4	4	4	3	0
Question 8	6	5	1	3	0
Question 9	5	5	5	0	0
Question 10	5	4	5	1	0
Question 11	4	3	7	1	0
Question 12	3	5	6	1	0

PMA

	A	B	C	D	E
Question 1	1	6	8	0	0
Question 2	2	6	7	0	0
Question 3	3	7	5	0	0
Question 4	2	9	4	0	0
Question 5	1	11	3	0	0

Section II

HMDD

	A	B	C	D	E
Question 1	2	2	8	3	0
Question 2*	1	(2)	5(5)	2(2)	0
Question 3	0	1	4	9	1
Question 4	1	1	4	7	2
Question 5	2	3	6	2	2
Question 6	3	4	8	0	0

PMA

	A	B	C	D	E
Question 1	3	4	6	2	0
Question 2	1	9	5	0	0
Question 3	0	3	4	5	3

Section III

HMDD

	A	B	C	D	E
Question 1	3	4	6	2	0
Question 2	3	4	8	0	0

PMA

	A	B	C	D	E
Question 1	1	7	7	0	0
Question 2	2	9	3	1	0

* ( ) Indicates test subjects who wore the keypad input device for the HMDD.

Appendix O: PMA Interviews

Background:
5. Radar, inexp
7. Radar, inexp
10. Engine Bay, inexp
12. Engine Bay, inexp
13. Engine Bay, inexp
15. Engine Bay, inexp
16. Radar, inexp
17. Radar, exp
18. Radar, exp
19. Radar, exp
20. Engine Bay, exp
21. Engine Bay, exp
22. Engine Bay, exp
23. Engine Bay, exp

****

Question 1: Is the information on the screen easy to read?

5. Yes.

7. Yes, quite clear.

10. Yes, but a little bit of it was breaking up. There was a line that interrupting the words on the screen. Other than that it was easy to read.

12. Yes, It was real easy to read

13. I thought it was.

15. Some of it was a little difficult to read. There was some horizontal lines that would disrupt the text.

16. No problems. It was real easy to read.

17. When there was a lot of text, it would be nice to have more spacing between tasks.

18. It was fine.

19. Under the test conditions, no I did not have any problems. I would be concerned under adverse flight line conditions. It might be nice to have a stand on it to adjust the tilt.

20. It was fine.

21. Very easy to read.

22. It was easy to read.

23. I had no problems. It was very easy to read.

****

Question 2: Give some examples of other activities that would be enhanced by using this device.

5. Yes, When you do a IMS drifting procedure. It is a step by step process. This device would be very helpful. Also when you are conducting a Maverick missile check. There are allot of switches that must be set in the correct order. If you get one switch off you can throw the whole thing off.

7. Trouble shooting activities that require you look up information in several different T.O.s. Using the branching function to go directly to the procedure. Saves downtime.

10. No. I can't think of any. Actually It would have been easier to perform the engine bay inspection with a checklist. In the engine bay, there was no place to set the computer down safely. I had to jump in and out to see what to do next. You could try to wear it over your shoulder ,but the way the strap is designed, you would have to read the screen upside down. Plus, you would be more likely to knock the screen against a fitting or something and break the screen.

12. Just about any job would be suitable. Especially if the job requires schematics or wiring diagrams.

13. You could use computer on anything that you do on the aircraft. You can't hold it all of the time, there are some operations that you can't hold a book the whole time.

15. I am still partial to the workcards. You are not afraid to get them greasy. You can wipe them off and stick them in your pocket. They are more portable.

16. For tasks that are in the cockpit the device would work real well. Activities that don't require you to move around allot to different areas of the aircraft. For example, drift checks.

17. I can't think of anything.

18. There could be allot of applications. The IMS alignment and drift test procedure would be a good one to use. The Inertial Measurement System alignment requires check certain points with the IMS at different settings. You then drift IMS system and watch for it to feel velocities or movement. We are required to record data every five minutes throughout

the drift cycle. The whole procedure takes about an hour. The rest of the operational checkout of the radar would also be a good test.

19. I thin'. it is unlimited as to what tasks it could be used for on the airplane.

20. The engine bay is a good example because you have to refer to several T.O.s. In most of my work, I use work cards. The work cards have only the minimum that you have to inspect during a phased inspection. That should not be "THE" inspection. Everything in the engine bay is subject to my inspection. The work cards are handy to have to make sure that you have checked specific items of interest.

21. Mostly with specialist. Guys who work in the cockpit. When they need to out in the weather and windy conditions. I can see this device being more useful on aircraft that are more complex. the F-16 and F-18 have allot more electronic equipment onboard. The maintenance tasks involved in those aircraft would require a larger amount of data in different T.O. volumes. Having all the data accessible from one screen would be a benefit.

22. None that I can think of.

23. Those tasks that require more than one T.O. would benefit from a device like this.

****

Question 3: What did you not like about the device.

5. Going from screen to screen was too slow.

7. Slow response time. easy to operate

10. It's size and its weight. It was nice that it had a big screen, but overall I thought it would be cumbersome to use.

12. Took a long time between screens. The size and weight may cause some people to avoid using it.

13. No it was fine. It was easy to operate.

15. Lack of durability, You don't want to damage it. It isn't as portable as workcards.

16. It worked real well.

17. The screen tended to lock up when I would press backup. The long processing time contributed to the problem.

18. No.

19. The slow response time and fact that there appears to be a heat problem that causes the system to halt. Also the problem with the system halting if the operator presses the next or backup command too many times in a row.

20. The size and weight are a disadvantage. Right now I can use work cards, that I don't have to worry about damaging, while I am performing the maintenance action.

21. In the case of an engine bay inspection, I didn't see a whole lot of advantage of using the computer. It is a good training device. Because I am so familiar with the workcards, I looked at the data on the screen and performed my checks. I didn't have to go back to the computer except for advancing to the next screen. When I do an engine bay inspection I look at everything in there. I don't just look at what is on the work cards.

22. It would have been nice to have something you could take into the engine bay with you. I like to have something with me. I didn't like having to crawl out each time to look at the T.O. I would be afraid of damaging the system. I needs to be made more rugged. I would be less likely to damage a paper T.O. When I was doing the inspection, I would read the three tasks on the screen and then perform them. It would have been nice to refer back to the tasks without having to go back out to the computer.

23. No. It worked fine.

****

Question 4: Were there any Visual problems with reading the screen (problems with glare)?

5. No. There was no glare.

7. No the operation was in the hanger, I had no problem with seeing the screen.

10. No. It was pretty good. I could read the screen from any angle.

12. No problem with glare. I think it was easier to read than if it were in print form. Plus you can read it at night.

13. No. It was cloudy out. I didn't have any problems reading it. I could read the text standing up. I tended to read it closer up so I wouldn't miss anything.

15. No. It was pretty readable.

16. There was some glare. I used my hand to get rid of the shadows so I could be sure to read the instructions correctly.

17. The position of the device created a situation in which the hanger's overhead lighting was causing glare on the screen.

18. No problems.

19. No I had no problems with glare.

20. It was fine.
21. No. I had no problems with glare.

22. No, it was legible. there was one part where it seemed bunched up. The words could be spaced out more.

23. No. If glare was a problem, it wouldn't be difficult to construct a hood to shield the screen. I didn't have any problem with it.

****

Question 5: Was the task you performed representative of maintenance activities you are asked to routinely accomplish?

5. Yes.

7. Yes.

10. Sure. It was a fair representation.

12. Yes fairly typical.

13. Usually the technicians perform the engine bay inspection.

15. Not so much the engine bay. Its not that often we pull a engine. For the regular guys it would be.

16. Yes we will do a radar checkout almost daily.

17. Yes it is one of the more common things we do.

18. Yes it may be to representative. I am very familiar with this procedure and tend to deviate from the T.O. instructions. When I do a radar checkout, I am looking for the rather obvious. When I get the debrief, I usually have a good idea as to where the problem is. I won't normally

perform the radar checkout as it is written in the T.O.

19. The task was pretty basic. Allot of the system checkouts would be more difficult than the fault isolation test.

20. Yes. If it weren't timed I would have taken half hour more. Usually you inspect the engine bay with the specialist there from the different shops. So as you are going through it with them you are inspecting the whole time they are inspecting. Then you go in and perform your checks.

21. Similar, yes. The type of inspection would be the same. I would normally inspect more of the systems in the engine bay.

22. Yes. It is my normal job.

23. Yes. The engine bay is one of those places where it is difficult to carry any T.O. material in with you regardless if it is a book or a computer.

****

Question 6: Looking at the manner in which we conducted the experiment, including the prebrief, instructions, eye examination, experiment, survey, and interview, would you like to see any changes made? Was the information adequate?

5. No.

7. No changes. Instructions were clear.

10. I thought all the instructions were clear and straightforward. It was easy to operate the computer.

12. It was satisfactory. It was real simple to use.

15. No. the instructions were satisfactory.

16. You might consider using schematics. Schematics would be useful for chasing down wires during troubleshooting. It would be easier than the fold out charts the T.O.s have. We don't chase down wires everyday but when we do this device would make it easier.

17. It would have been nice to have a dry run to get used to using the device and the test environment.

18. No.

19. No.

20. No.

21. I would you try a wider application. I would test more of the computer's capabilities.

22. Your eye test is for long distance. I think that it would be better to test vision close up.

23. The test article could have had higher fidelity. Because this aircraft is a hanger queen. It tends to have parts cannibalized off of it. So when you are doing the inspection, you are not certain if things missing from the aircraft is considered a discrepancy or is the result of the aircraft not being operational. An operational aircraft I would be able to spot the discrepancy right off.

****

Question 7: Do you have any other questions or comments?

5. No.

7. No.

10. No.

12. No.

13. The concept is a good one. You might see if there could be a radio link to a base computer for checking the maintenance history of that airplane. The unit seems small enough that it will fit in the cockpit or you could hang it by the strap.

15. You should look at making the system smaller. If it was palm size, then it could fit in your pocket. More work card size.

16. No.

17. No.

18. I thought that the crystal screen was broken up at times. There are lines that interrupted the text. The text was still readable. It would be more of a problem with a schematic.

19. Just that when the bugs get all worked out, it will be a good system.

20. I can see an advantage to having the computer would be the ability to update T.O. much more quickly. Sometimes we are a week behind in placing all of the updates into the

T.O.s. By using a computer I could make the updates much more quickly.

21. I would think the HMDD would be more of a hinderance than the hand held computer. You can set aside the hand held when you are not using it.

22. No.

23. No.

Appendix P: HMDD Interviews

Background:
1. Radar, dominant eye, inexp
2. Radar, dominant, inexp
3. Radar, dominant, inexp
4. Radar, non-dominant, inexp
8. Engine bay, non-dominant, inexp
9. Engine bay, non-dominant, inexp
11. Engine bay, dominant eye, inexp
14. Engine bay, dominant eye, inexp
24. Radar, dominant eve, exp
25. Radar, dominant eye, exp
26. Radar, dominant eye, exp
27. Radar, dominant eye, exp
28. Engine Bay, dominant eye, exp
29. Engine Bay, dominant eye, exp
30. Engine bay, non-dominant eye, exp
31. Engine Bay, dominant eye, exp

****

Question 1: Is the information on the screen easy to read?

1. Yes, it was.

2. Yes and no. It was easy to read as long as I had a clear image of the screen. I had to keep adjusting it. It would have been easier if there was a larger boarder around the information. The edges were the toughest to read.

3. Yes. I had problems focusing on the full range of information. I wear no line bifocals and I was unable to see the whole screen clearly. If I moved it around, I could see read all of the text.
4. It was when the screen was adjusted correctly.

8. The text was O.K. but at times it seemed the text run together however. The letter W and letter H were hard to read.

9. Yes.

11. Once I used to focusing on the screen yes. Placing the screen closer to eye made it easier to see the whole screen. At first, I could not see the top left hand part of the screen.

14. Yes

24. It was excellent.

25. It was fairly easy to read.

26. I had a hard time focusing. I wear reading glasses and it was difficult for me to read the screen with it being so close to my eye.

27. I found the information easy to read.

28. It was fine.

29. I had problems get it adjusted so I could read the text.

30. It wasn't too bad. I could read it.

31. It was little bit. It was a little too close for me. I am far sighted so I had a hard time focusing.

****

Question 2: Give some examples of other activities that would benefit from using this device.

1. Any time you are out in the weather this device would be preferred over a paper T.O. It would be especially helpful for the guardsmen. We come out once a month and it is nice to have a reference tool. T.O. are difficult to use if you are not familiar with them.

2. Anything where you would need to be balancing yourself. Any situation where you need to keep you hands free. Specifically any radar checkouts where you need the information right there in front of you.

3. Checking the PAVE PENNY (laser guided system) general radar checks, any work with the onboard computer.

4. Performing a Maverick check maybe a possible activity. It requires somebody in the cockpit and somebody on the ground at the same time. The HMDD would make it possible for both people to see what is going on. It would be better than yelling back and forth because you have to wear a head set allot of times.

8. It might be useful on a combat turnaround because we are working real fast and we don't have time to pull out a chart to see what to do next.

9. I would limit it to inspections only.

11. For my activities it would be a hinderance. It does not provide any real advantage of something you could set on the ground.

14. Pretty much anytime we use a T.O. this device would give us quick access to the information. Better than looking back

and forth through the pages. A lap top you have to worry about dropping it, Using this device you would be less likely to damage it. Most of the time you want to keep your hands free to do the work. By not having the device on you, the laptop computer is another piece of equipment you have to worry about safeguarding.

24. I can't think of any. I am set in my ways. I have been doing my job for 16 years with a book in front of me.

25. When you are out looking in the radome itself, it would be handy to have the HMDD. Anytime you are working outside the aircraft when it is windy.

26. This device would be useful for anytime you have a T.O. page that involves foldout pages. You could read the tech data and view the hardware at the same time.

27. I would be great for special activities. I wouldn't use it for routine operations that you perform all the time. I would use it more for troubleshooting complex equipment.

28. I can't think of any. It would be easier to use a book.

29. For my self, I thought it hindered me. I felt like I had only the use of one eye for inspecting the hardware.

30. Engine bay is a good example. Any place where you would do inspections.

31. Any task where you need to move around allot.

****

Question 3: What did you not like about the device.

1. It was cumbersome. There seemed to be allot of bulk especially the headset. It wasn't anything major.

2. If I was out in 95 degree weather, that vest would have been unbearable. The equipment on the back is uncomfortable when sitting.

3. I felt it was a little bulky. I understand it is a prototype.

4. I had some problems adjusting the eyepiece there in the beginning. It took awhile to get it just right. The pack was getting hot there in the end.

8. It seemed that the locking arm was a little cumbersome. Also the tilting of the text inside the screen has hard to adjust it just right.

9. I would be concerned with extended wear of the device as well as wear during adverse weather conditions. If it is 100 degrees outside, I couldn't imagine wearing the headset for a few minutes let alone over an hour.

11. It took awhile to position the screen. The device seems to be in your way. It blocks your eye.

14. It took awhile to get used to. If I could put it on my dominant eye, it may have been easier to focus. When I was inspecting a dark area I would have a hard time focusing past the eyepiece.

24. I disliked the bulk of the headset and the glare on the screen. I would be concerned on how much abuse it could take.

25. Using the system inside the cockpit is a bit uncomfortable. The battery pack and stuff on the back got in the way.

26. I had trouble seeing the instruments in the cockpit.

27. I disliked the display blocking my vision. I had difficulty in viewing the fault location switch with the device on. It may be that I wasn't used to wearing it.

28. I disliked the weight of the headset and having the eyepiece right in front of my field of view.

29. I thought it blocked my vision. If you had to wear it for extended period time, it would become hot.

30. I noticed it has a real high frequency flicker. It was annoying after awhile.

31. The actual screen text looked crooked in the lens. That was distracting.

****

Question 4: Were there any Visual problems with reading the screen (problems with glare)?

1. No.

2. I had problems reading the text in the very top and bottom of the screen. I had no problems changing the depth of field when viewing the text and the cockpit instruments.

3. No. I did notice that I would close my other eye when

viewing the screen.

4. At first I had to squint because I wasn't used to distinguishing the background from the image displayed in front. After awhile, I was able to view the screen through the background.

8. No.

9. When I looked out from the engine bay to the outside, the bright sunlight completely wiped out the screen. I could see it fine as long as I was facing the engine bay, away from the sunlight.

11. I had no problem with glare. I had difficulty in focusing on objects.

14. I did until I moved it closer to my eye. I was getting reflection off my glasses.

24. I had problems with the glare. I had to position my head so I could read the screen without the light bouncing off the screen.

25. It took a little while to get used to the eye piece. After the first couple screens, it was easier to focus. I didn't have any problem with glare.

26. When I was trying to adjust an instrument in the cockpit, it was difficult to see it because of the light in my dominant eye. Maybe a switch to turn the screen off would be useful.

27. I found that I was closing one eye to read the screen. I had difficulty in reading the screen with both eyes open.

28. No.

29. There seemed to be allot of background glare.

30. No.

31. No.

****

Question 5: Did you suffer any headaches or eye strain from using the device?

1. No. I am feeling a little stress from using the HMDD. It is probably from switching from looking close and then far.

2. Yes while trying to read the text in the marginal areas I was experiencing some eye strain.

3. No.

4. No.

8. No.

9. Just a little. Things appear brighter through my right eye(eyepiece was on the right eye) than my left. My right pupil might slightly dilated.

11. No.

14. No.

24. If it had gone on for a longer period of time, I might have. I am a little tense now.

25. No

26. No.

27. No.

28. A little bit of eye strain. No headache though.

29. No, not really. If I had to wear it longer, I think I would have some eye strain.

30. No.

31. No.

****

Question 6: Did you have any problems with the headband?

1. No.

2. It is a little bit on the heavy side and it makes you sweat.

3. I could feel the weight but it wasn't a problem.

4. It was O.K. It didn't seem too heavy.

8. Though I had the headband on tight, it seemed that the headset would start to fall off when I looked up. It seemed top heavy.

9. It is fine when you are not wearing anything else on your head. It might be hard to wear with ear protectors and or goggles.

11. The headband seemed a little heavy. It would slip every once and a while.

14. When I got it tight enough that it wouldn't move, it became uncomfortable to wear after awhile. I needed it steady since I was climbing around. I did not have any problems with it moving around. It would have been nice to be able to move eyepiece around incrementally instead of locking it in place.

24. No problem. It fit O.K.

25. Yes, it was too big. I couldn't adjust it down enough to fit. I could wear it with a baseball cap however.

26. No.

27. I disliked the whole mechanism. It seemed very bulky.

28. The fact that it weighed too much and you had to have something on your head.

29. There was some problems with getting the adjustments just right so I could read the screen.

30. It moved around a little bit. I banged it a couple times. I don't think I had it tight enough. The eyepiece stayed in place fairly well.

31. It tended to slip a bit when I tilted my head back. I had to adjust several times while I was working.

****

Question 7: Did you have any problem with the vest?

1. No, not really. It was a little cumbersome but not restrictive.

2. No. It didn't get in the way.

3. No.

4. No. It seemed all right. The weight wasn't a problem, it seemed to weigh about the same as a bulletproof vest would.

8. It seemed O.K. I didn't like having the keypad on my arm. I would be afraid of rubbing it up against something without knowing.

9. I was surprised that it didn't take any time to adapt to wearing the vest. It fit comfortably and wasn't as heavy as it looked. It wasn't as cumbersome as I had perceived it

would be. I wouldn't want to have to do maintenance activities with the vest on because the vest would reduce my access into small compartments. Also I would be concerned with leaving FOD in a critical part of the aircraft. The vest adds to amount of things that can get hung up or drop off into aircraft compartments.

11. It seemed to get warm on the lower portion of the back. The weight was distributed fairly evenly. It was comfortable to wear.

14. The vest was warm. It wasn't a function of the electronic's generating heat but more a function of me moving around with it on. You may consider making the vest out of a mesh.

24. I liked the key pad on the biceps. That was handy to use.

25. It seemed fine. When you sat in the cockpit, you knew you had the battery packs were there. It wasn't unbearable, just a hinderance.

26. No.

27. It was all right. I just don't like having extra things on while I am working.

28. I preferred to have the keypad on the vest instead of on my bicep.

29. It seems bulky and the batteries don't last long enough. Once it was adjusted it stayed in place fairly well.

30. I used the pistol grip input device. I would prefer the keypad on the arm band.

31. It was a little hot in this weather. It seem distributed pretty well.

****

Question 8: Was the task you performed representative of maintenance activities you are asked to routinely accomplish?

1. Usually, you would have a partner outside the cockpit to help examine the airplane and radome.

2. Yes.

3. Yes.

4. Yes.

8. Right now we don't do allot of engine inspections, we don't do allot of. But when we get the F-16 we will be doing more of them.

9. No. It is a specialty function. We perform phased inspections periodically. It is not a daily activity. Most of the work is on schedule and you have to work as fast as you can get the planes turned around. An engine bay inspection is not a time critical maintenance action. There is no real time limit.

11. I have never performed an engine bay inspection. This was the first time I have been in an engine bay. If I was full time, I might have more experience with the task.

14. Yes.

24. Yes, very much so.

25. Yes, anytime we have a write-up on the radar we perform the fault isolation test first.

26. Yes.

27. Yes.

28. Yes.

29. Yes.

30. Yes, it seemed to be realistic. If you were worried about bumping it around or snagging it on something, the engine bay is a good place to test it.

31. Yes.

****

Question 9: Looking at how we conducted the experiment, including the prebrief, instructions, eye examination, experiment, survey, and interview, would you like to see any changes made? Was the information adequate?

1. It seemed like some instructions were a little vague. I was not familiar enough with all the controls to be sure what the instructions were asking me to do.

2. No, it seemed to go fairly well.

3. It would have been nice to have pictorials. As guardsmen, we are not that familiar with the systems being tested.

4. No, I think you made everything pretty clear. I didn't feel pressured to do anything difficult. The operation of the device was simple to learn.

8. No,the operation was fairly simple. There wasn't that much training needed.

9. When I was active duty I worked for the 3246 Test Wing at Eglin AFB for a period of time. So, I have experience with testing, and I thought the test was conducted fairly well.

11. The briefings were clear. I understood what was expected of me.

14. None that I could think of. It was very easy to use.

24. No,it all seemed fine.

25. Maybe the display could have a battery monitor so you could tell when you were getting low on power.

26. No.

27. No, it was fairly clear what was expected.

28. No.

29. It seemed satisfactory to me.

30. No.

31. No, it was a good format that you presented.

****

Question 7: Do you have any other questions or comments?

1. This would benefit traditional guardsmen quite a bit. Normally the technicians who work here full time walk us through the procedure. We rarely review the T.O. It is too difficult to use. Your device would place us in more of a control position.

2. No.

3. Some newer troops may not know where all the switches are. It might help them if you provided a pictorial of what the switches are.

4. In using the fault locator switch in your test, it was nice to turn the fault locator switch and look at the HMDD screen without having to turn all the way round back to check the T.O. data. The information was right there. The

pistol grip was easy to use because you didn't have to look at it to push the correct button. You could do it by feel.

8. No.

9. On postflight and preflight inspections you have an intake and exhaust portion. It would be difficult to perform these inspections while wearing the HMDD. On the engine exhaust postflight inspection you are laying down inside the engine to check the mixture nozzle, temperature nozzle, and aft blades. You would have a hard time insuring the HMDD components wouldn't snag any of the engine parts. On the F-16, there is more room. You can do the inspection on your hands and knees. The intake inspection is the same way. You have to crawl into the engine to inspect the air temperature probe, stater blades, variable inlet guide vanes, oil struts, compressor blades, seal. Generally, we would not even take our job guide with us when inspecting the inlet. In fact, we had a policy to take off our boots before inspect the inlet. So if you were using the HMDD you would have to remove it for the inspection and put it back on afterwards. That is allot of extra work plus there is an increased chance of damaging the system in the process.

11. It would have been helpful to have drawings of what to inspect. What are the items being asked to be inspect.

14. You may look at using a heads up display. You could be able
to see through the information. As long as the device is durable and more lightweight it would be useful in viewing T.O. data. The higher complexity the task the more likely that this device would be useful.

24. No.

25. You might look into putting a pause function in the system so you could extend the battery life when you are not reading the screen.

26. You may consider using a quick disconnect to the vest and use aircraft power for running the device. We use a similar connection when operating the doppler ground speed box. We plug it into the receiver/transmitter and run the cable up to the cockpit. The problem with batteries is that they can go out at an inopportune time. It seems to me that batteries are too unreliable to be the sole source of power.

27. I may have done better with the screen placed over my non-dominant eye.

28. No.

29. Just for my own personal use, I don't think it would work very well for me. I would prefer the other computer so that I don't have anything blocking my vision.

30. I am concerned on how long the batteries last. Also I am not sure how well the system would work in adverse weather. If it's cold out, the screen may tend to fog up from your breath.

31. I don't think the device would work with chemical warfare gear on. The main problem would be the vest. You would not have enough room to place the eyepiece under the plexiglass shield.

Appendix O: Survey Responses Histograms

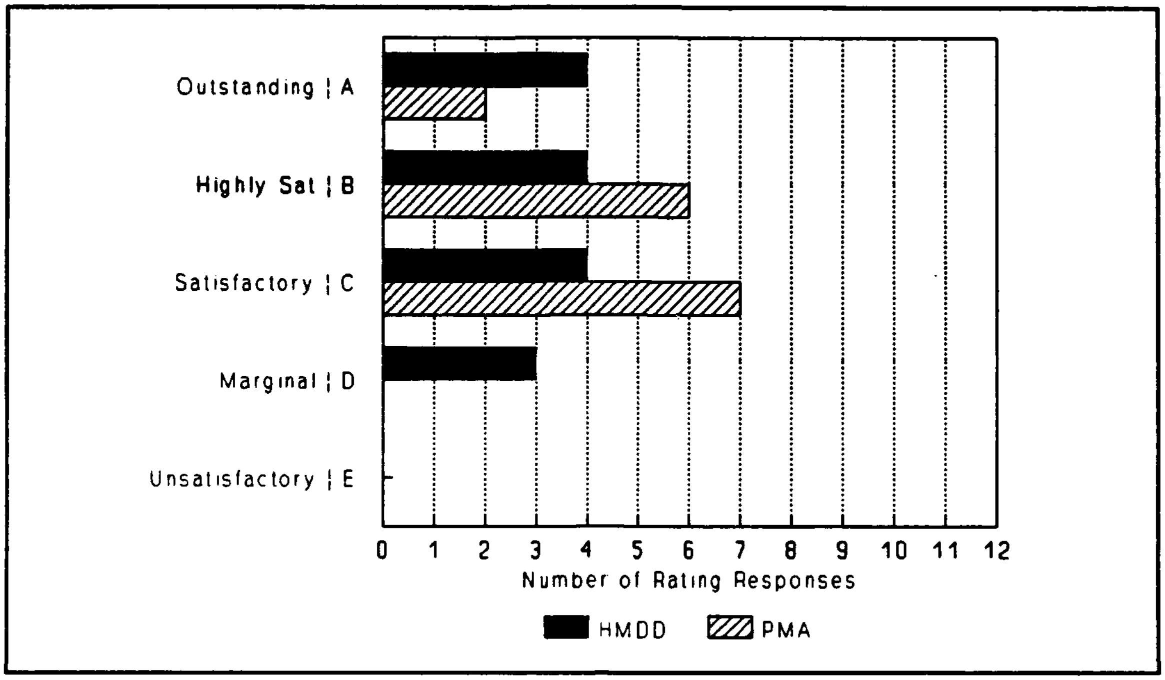

Figure 20. Readability of Information

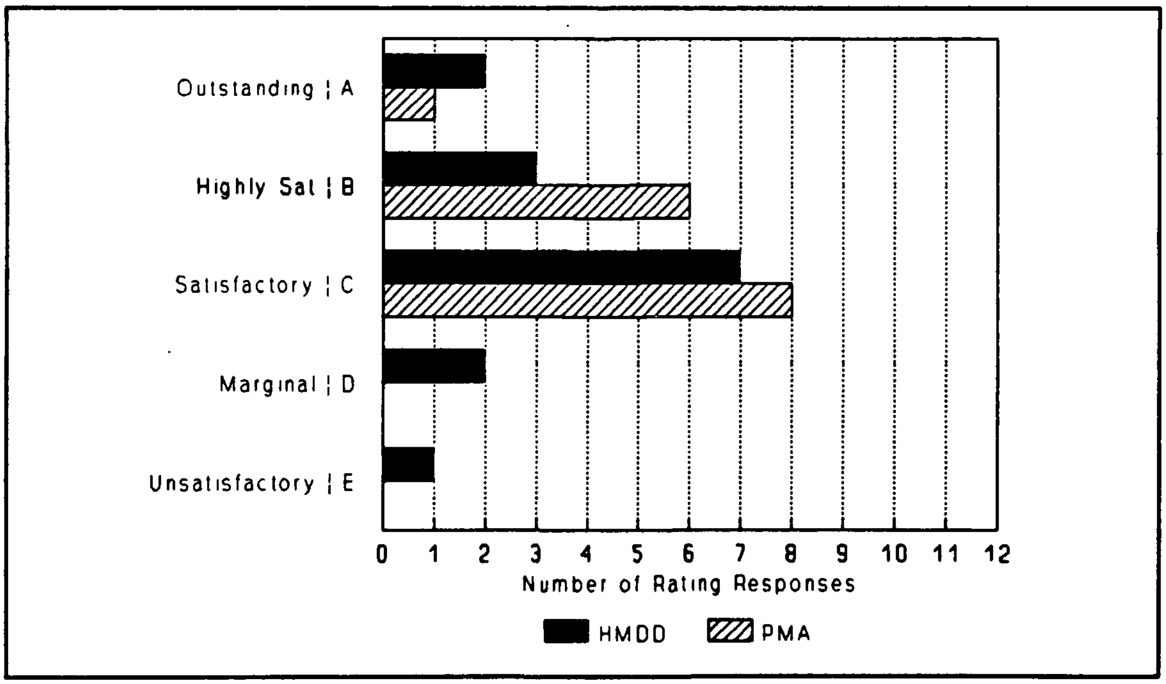

Figure 21. Glare on the Screen

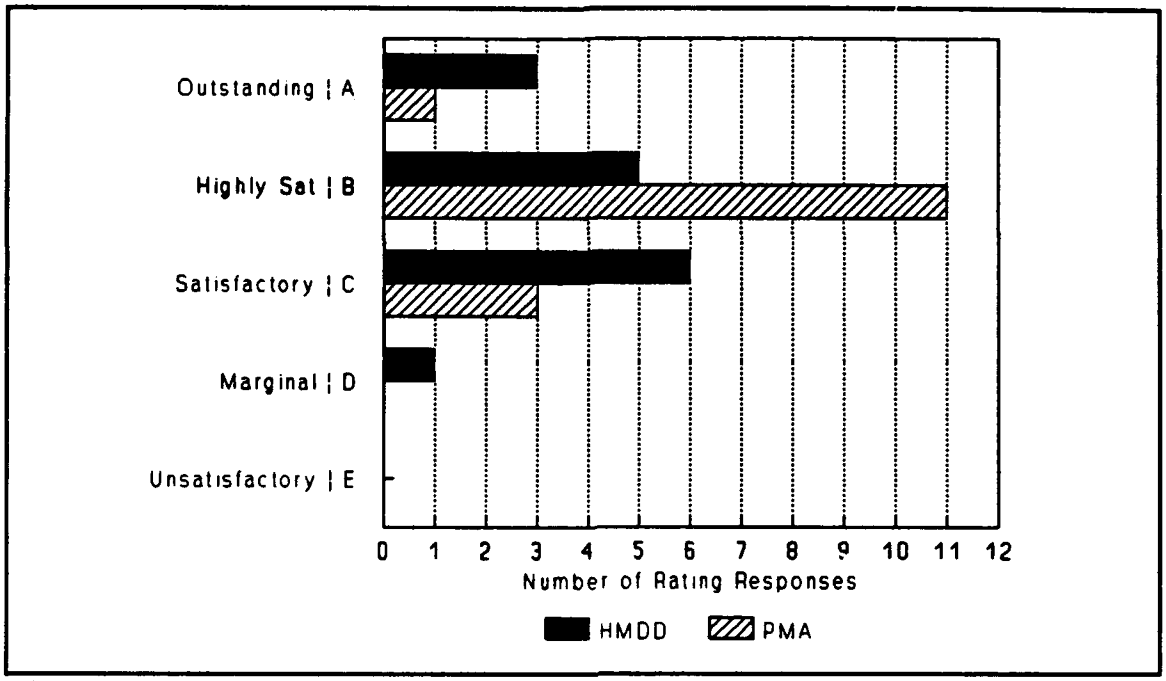

Figure 22. Display Brightness

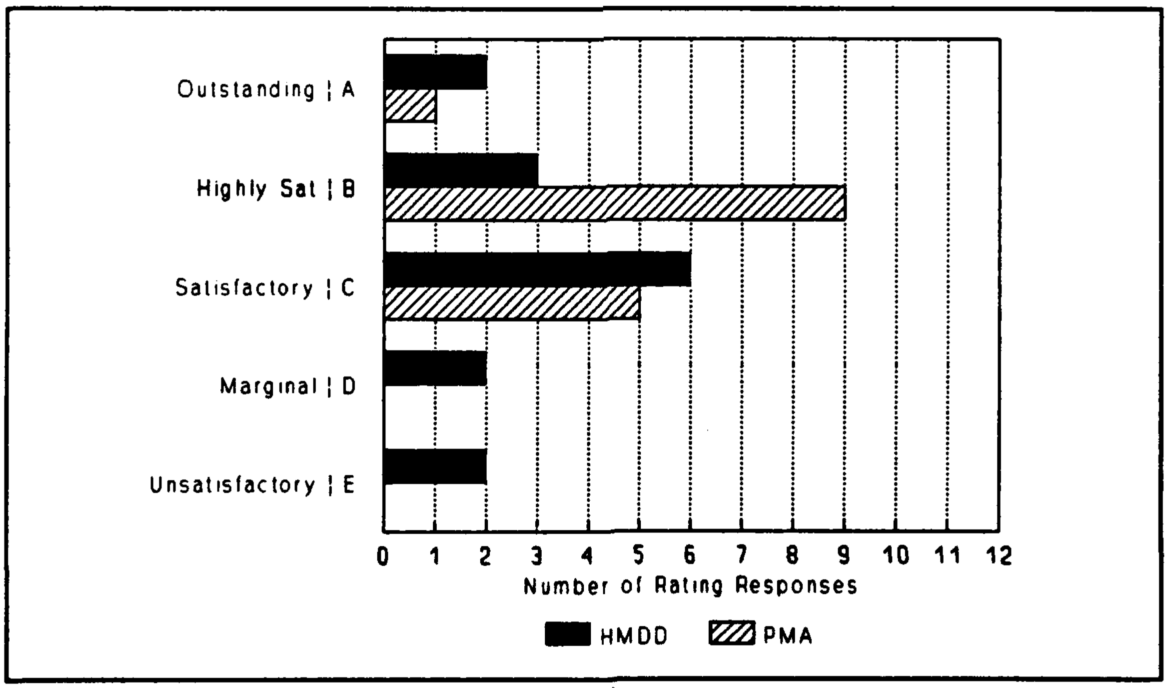

Figure 23. Adequacy of Screen Size

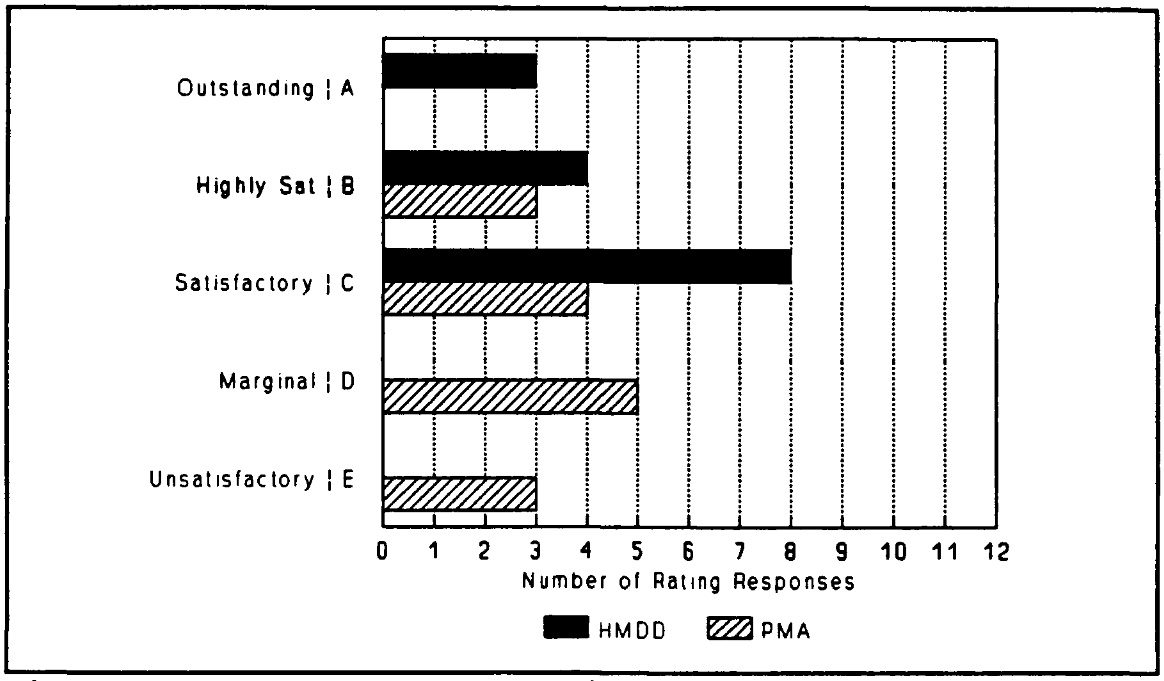

Figure 24. Computer Response Time

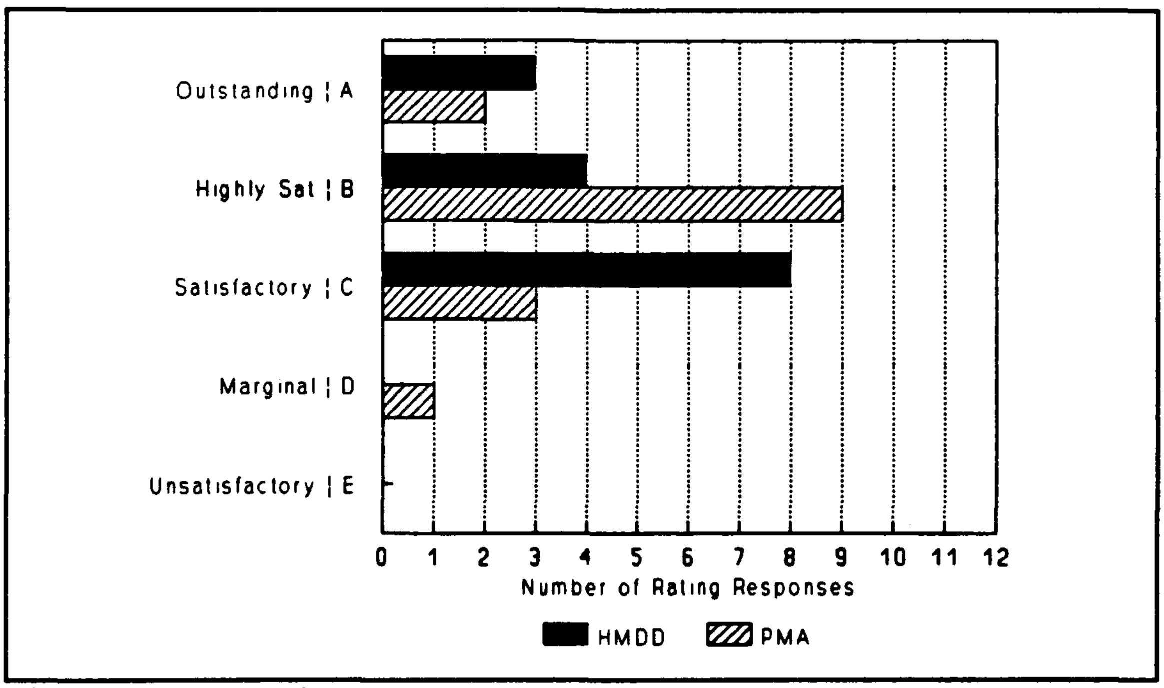

Figure 25. Spacing of Information

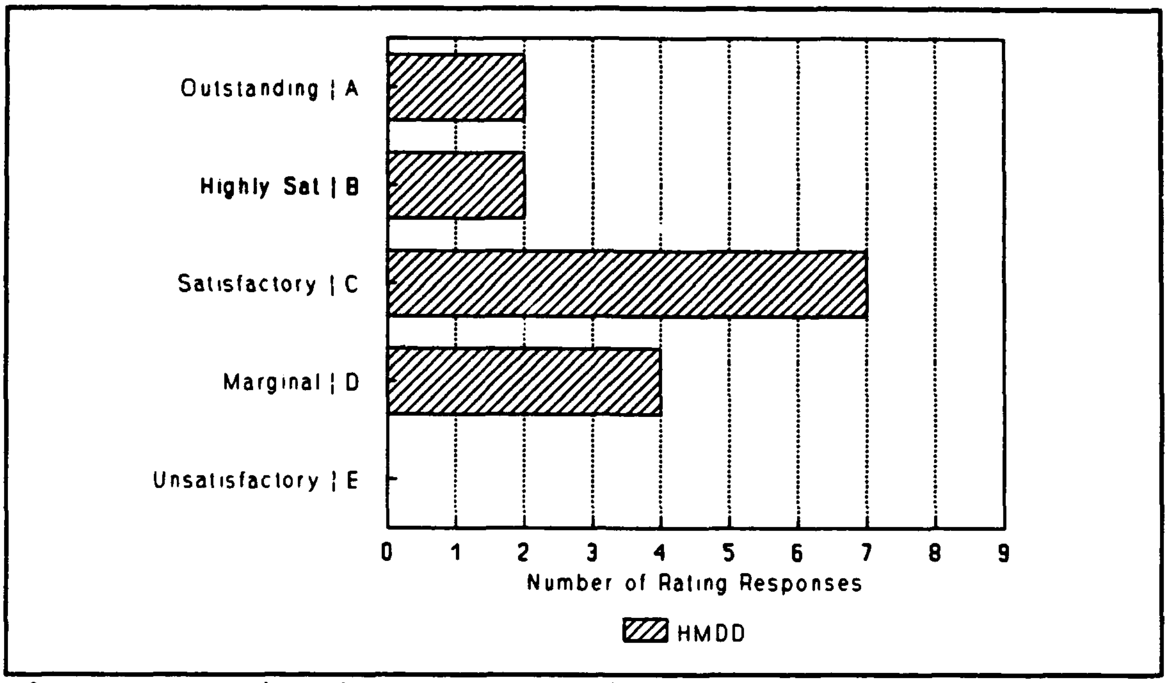

Figure 26. Switching the Attention from the HMDD to the Work

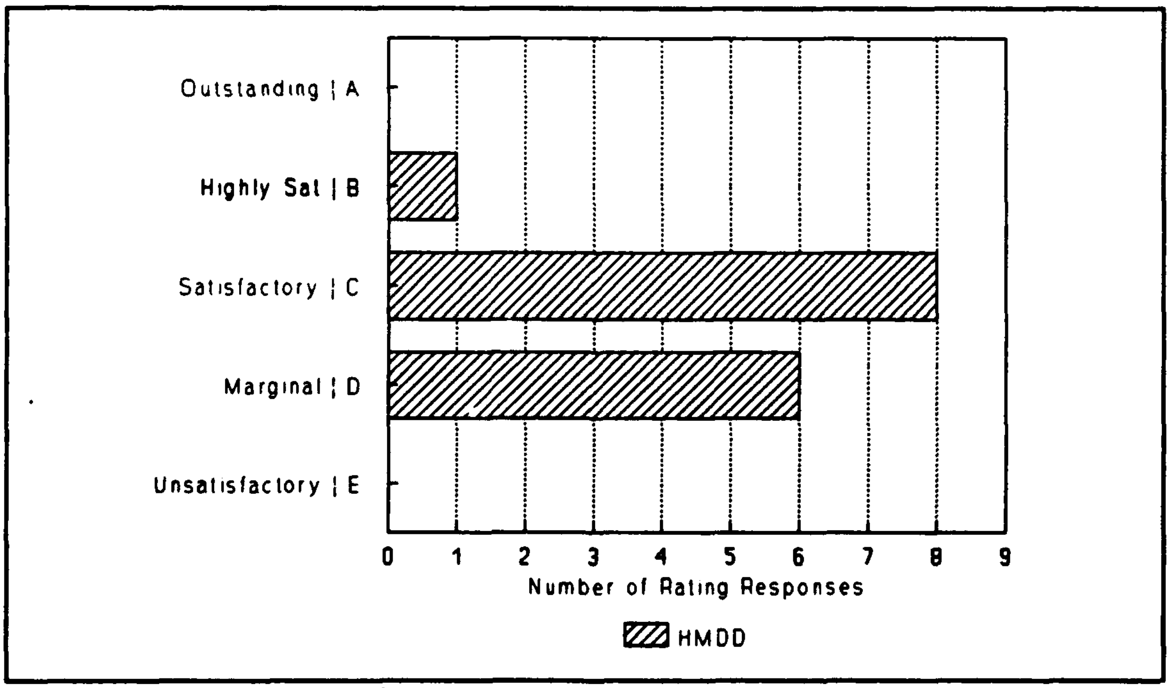

Figure 27. Eye Strain from HMDD Use

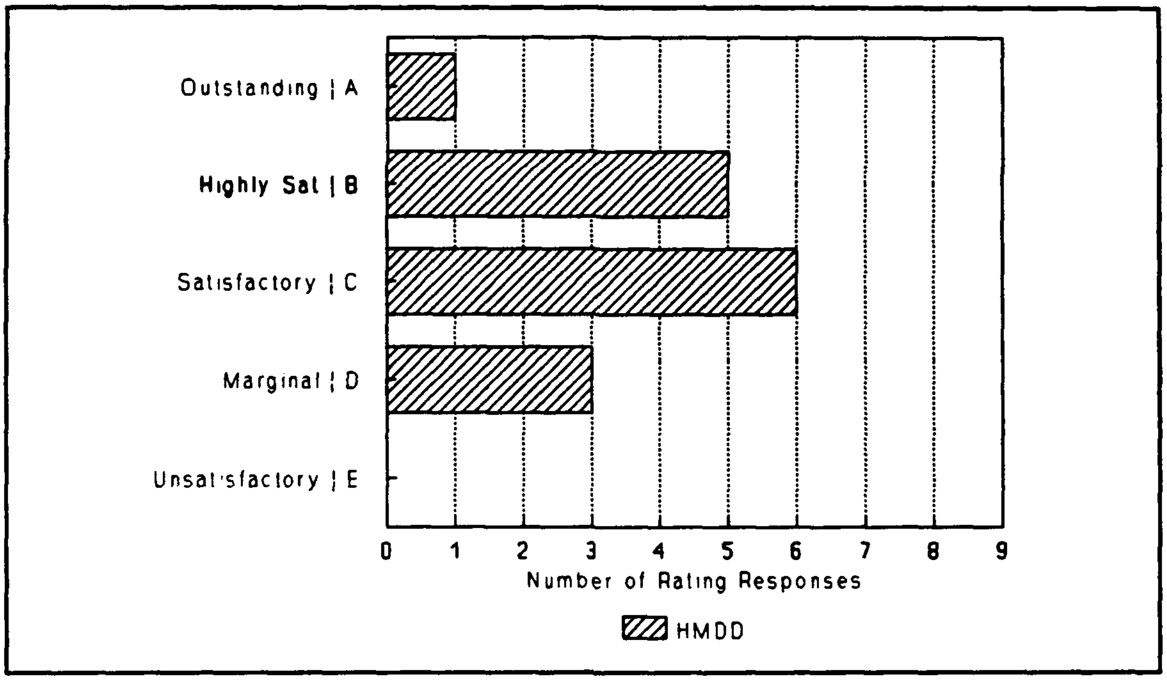

Figure 28. Blurring from HMDD Use

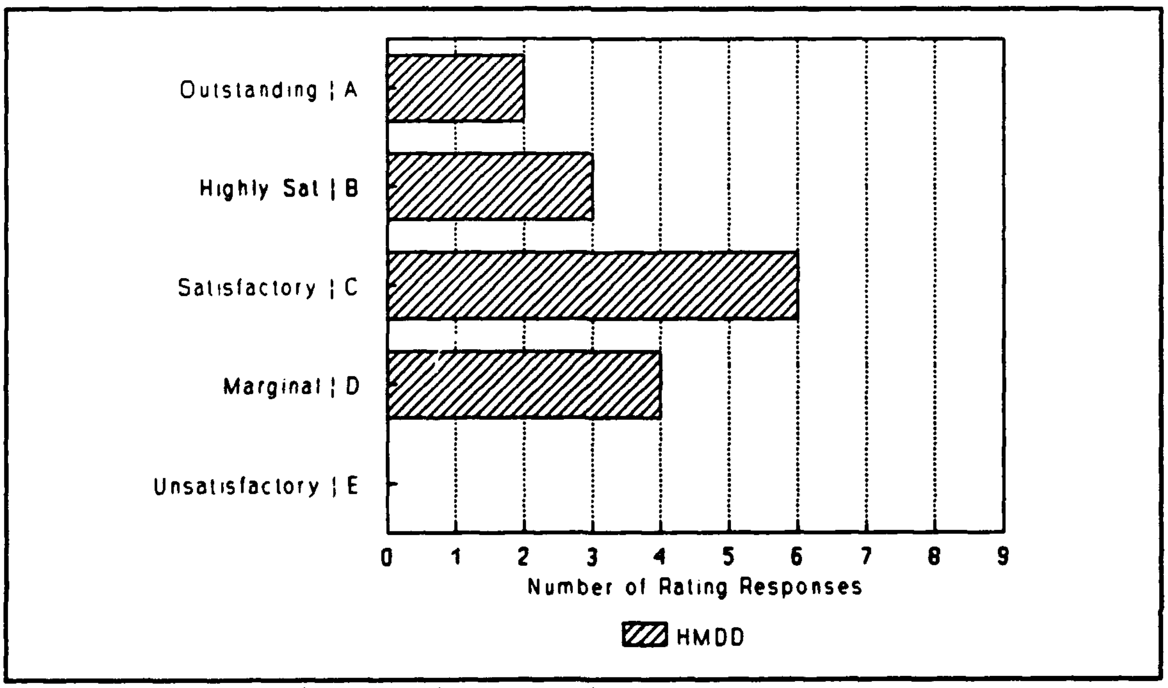

Figure 29. Difficulty in Focusing from HMDD Use

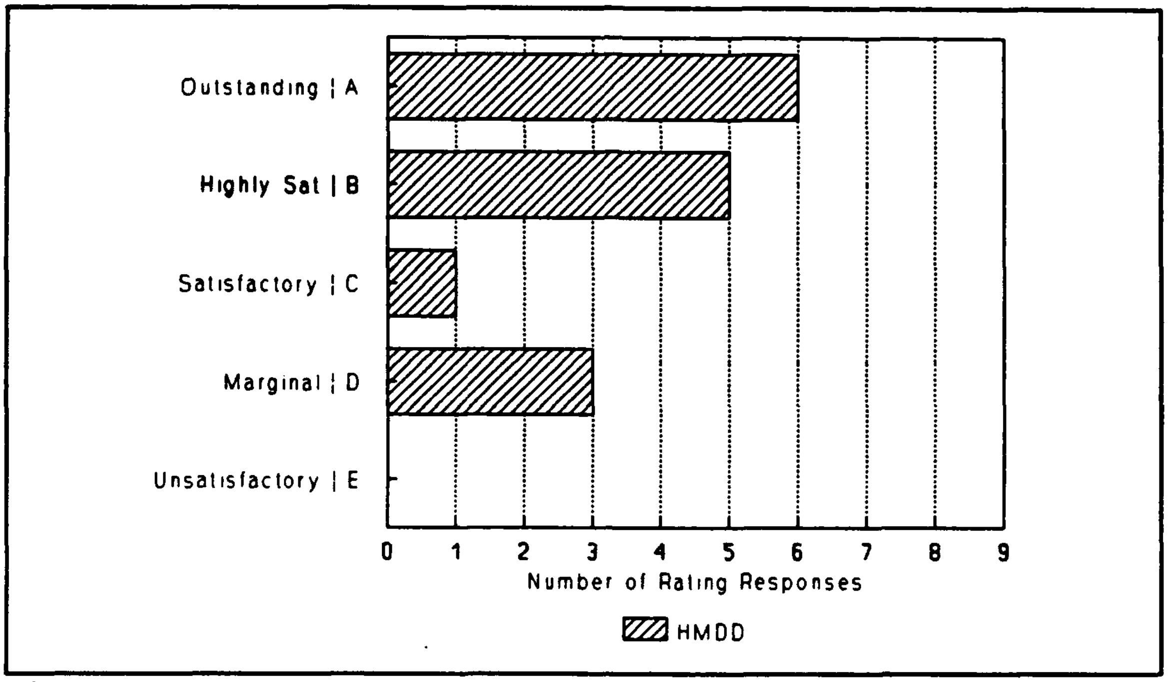

Figure 30. Presence of After Images from HMDD Use

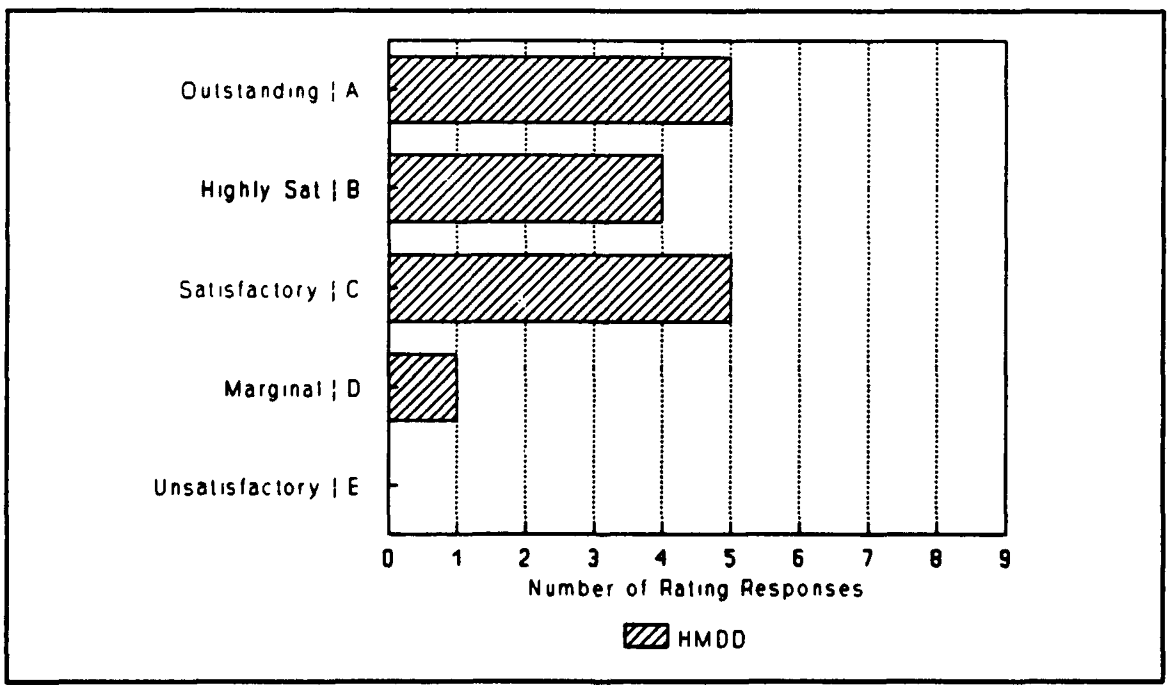

Figure 31. Headaches from HMDD Use

Bibliography

Becker, Al. "Design Case Study: Private Eye," Information Display, 8-11 (March 1990).

Box, George E.P. and others. Statistics for Experimenters. New York: John Wiley and Sons, 1978.

Department of Transportation. Human Factors in Aviation Maintenance Phase I: Progress Report. Report No. DOT/FAA/AM-91/16. Washington DC: Government Printing Office, 1991.

Devore, Jay L. Probability and Statistics for Engineering and the Sciences. Pacific Grove CA: Brooks/Cole Publishing Company, 1991.

Drury, C. G. and others. "A Method of Evaluating Inspector's Performance Differences and Job Requirements," Applied Ergonomics, 20.3 (September 1989).

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

Galitz, W. O. Handbook of Screen Format Design. Wellesley Hills MA: QED Information Sciences, 1985.

Hale, Steven and Dino Piccione. Pilot Performance Assessment of the AH-64A Helmet Display Unit. Fort Rucker AL: Essex Corporation, January 1990 (AD-B140472).

Heleander, Martin. Handbook of Human-Computer Interaction. New York: Elsevier Science Publisher B.V., 1988.

Masquelier, Barbara L. Comparative Evaluation of Monocular Display Devices Relative to Portable Computers for Display of Aircraft Maintenance Technical Data. MS thesis, AFIT/GSM/LSM/91S-18. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1991 (AD-B161858).

Matthews, Michael L. and Karin Mertins. "The Influence of Color on Visual Search and Subjective Discomfort Using CRT Displays," Proceedings of the Human Factors Society 31st Annual Meeting. 1271-1275. 1987.

Montgomery, Douglas C. Design and Analysis of Experiments. New York: John Wiley and Sons, 1976.

Nugent, William A. and others. Troubleshooting Performance Using Paper and Electronic Documentation. Naval Personnel Research and Development Center, San Diego CA, September 1987 (NPRDC TN 87-41).

Pappas, Paul. An Analysis of Fixed Wing Tactical Airlifter Characteristics Using an Intra-Theater Airlift Computer Model. MS thesis, AFIT/GLM/ENS/91S-50. School of Systems and Logistics, Air Force Institute of Technology (AU), Wright-Patterson AFB OH, September 1991 (AD-A246908).

Rash, Clarence E. and John S. Martin. 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, August 1988 (AD-A202984).

Schwind, Gene F. "Hands Free; Eyes Free," Material Handling Engineering, 26 (March 1990).

Sheedy, James E. "VDTs and Vision Complaints: a Survey," Information Display, 8 (April/May 1992).

Shepherd, William T. "Human Factors in the Maintenance and Inspection of Aircraft," Proceedings of the Human Factors Society 34th Annual Meeting. 1167-1170. 1990.

Tannas, Lawrence E. Flat-Panel Displays and CRTs. New York: Van Nostrand Reinhold, 1985.

Thomas, Donald C., Chief Scientist, Combat Logistics Branch. Personal Interview, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, 20 June 1990.

Vita

Jeffrey A. Friend came into this world with his twin brother on June 5, 1959. Jeff graduated from Olympus High School with honors the summer of 1977. He earned his Bachelor of Science degree in Aeronautical and Astronautical Engineering from the University of Washington in August 1981. Jeff started his professional career with the Air Force as a propulsion project manager of the Peacekeeper ICBM fourth stage at the Ballistic Missile Office, Norton AFB, CA. Then in September 1985, he became a member of the first Air Force team to conduct Defense Satellite Communication Systems satellite on-orbit operations at Onizuka AFB, CA. In January 1987, Jeff relocated to Colorado Springs where he served as Deputy Flight Commander at the 3rd Satellite Control Squadron, Falcon AFB, CO. Each flight was responsible for real-time command and control of over 23 DoD communication satellites. In June 1990, he was selected to be the Deputy Chief of the Satellite Operations Division at Air Force Space Command Headquarters. In May 1991, he was accepted to attend the Air Force Institute of Technology Graduate Systems Management program.

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As military developers provide increasingly complex weapon systems, it becomes more difficult for maintenance technicians to perform their jobs. One aspect of the technicians' world is the need to access technical information in the performance of their duties. This study investigated two electronic display systems to evaluate which enhanced technician performance more. A Head Mounted Display (HMD) device and a portable hand-held flat-screen computer were evaluated in the performance of two flightline maintenance activities. Although both display systems were fully portable and self contained, only the HMD system allowed continuous access to technical information during task performance. In most cases, technicians using the HMD system outperformed those equipped with the flat-screen computer system in terms of effectiveness and efficiency.

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