IETM Usability: Using Empirical Studies to Improve Performance Aiding

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Abstract

Substantial expectations have been set about the effectiveness and role that high level Interactive Electronic Technical Manuals (IETMs) for performance aiding will play in enabling lesser skilled U.S. Navy maintainers to perform their jobs. This empirical study about the design and effectiveness of high level IETMs provides baseline and comparative data about two high level IETM interfaces used for one F/A-18 aircraft maintenance task. Eight maintainers whose experience levels varied from new (less than one month) to very experienced (more than eight years) participated in this study. Both baseline and "with IETM" data collection efforts occurred at China Lake Naval Weapons Station. Study results include performance data and insights about needed improvements to attain correctness, speed, and ease of use in information search, navigation and magnification activities. Differences in expert and novice preferences and performance were documented to inform future adaptive interface design efforts. The maintainers who participated were unanimously enthused about the possibility of having improved IETMs on small mobile computers for performance aiding in the near future.

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I. Introduction

As noted at the U.S. Navy Workshops on the Generalized Maintainer, aircraft carrier and aircraft maintenance for the U.S. Navy is changing today in three key operational aspects: (1) paper documentation is being replaced with Interactive Electronic Technical Manuals (IETM's), (2) the number of personnel performing the work is shrinking, and (3) the amount of specialized training maintainers receive to keep aircraft and ships at full operational readiness is being reduced. These changes are also occurring in the other military services and the civilian aircraft sectors.

The Navy and all the military services are challenged to make these changes while meeting an ambitious time schedule. The study we report on in this document is directly applicable to attainment of the Navy's objective to improve training and performance aiding. Currently, there are substantial unknowns about both the effective authoring of IETMs and their use in maintenance training and performance aiding. Of greatest importance is the need for knowledge about how IETMs, communications capabilities, and computer technology can support Navy maintainers to effectively use IETMs while in combat and other operational situations. This basic empirical study and others like it are essential for the Navy to have underway now so that objectives for improved training and performance aiding can be accomplished without adversely impacting force readiness.

The next section (II) of this report summarizes insufficiencies of current IETMs for performance aiding identified in this study and a description of the IETM problems that fall within the scope and focus of this study. Section III presents the study procedures and design. Section IV presents the results of this effort. Section V presents the conclusions and recommendations from this study. Appendix I contains the initial demographic data collection instrument and Appendix II has the post-trial self-report questionnaire used in the study. This document is accompanied by a CD-ROM containing video clips of maintainers' performance as referenced in this report. The videos are formatted as Quick-time movies for viewing on either PC or Mac platforms.

II. Insufficiencies of Current IETM Interfaces

Numerous problems with currently available Level IV IETMs were identified during the initial phase of this project. First, there was no attention to adaptive interfaces that would take into account the varied experience levels of users. Second, in spite of Navy Standards to promote effective IETM development, it appears that these Standards, e.g., MIL-PRF-87268A (1997) do not result in development of IETMs that take into account several crucial aspects of human usability. Third, the design of current IETMs requires that maintainers use precisely correct nomenclature or the system does not find/link them to needed information. Fourth, the use of IETMs in Personal Computers (PCs) often involves problems related to hardware, display technology, Input/Output devices, and Operating Systems. It is almost impossible to divorce the effects of the overall computer system from an understanding of IETM design and usability issues. For this study we did, however, focus on five key aspects of interface design that are described below. Then we detail the prioritization of these aspects that we addressed in the interfaces tested in this study. The solutions we prototyped and tested are described in Section III of this report.

1. Windows-related Features

There are a number of interface elements that are inherited by default. For experienced computer users, they are expected features. However, for IETM users, they are unnecessary. Given the low level of computer literacy found with the participants in this and several other recent user tests conducted with military maintainers, Windows-related features present a serious potential source of difficulty and error.

When designing an interface for novice users, it is very important to provide only the interactive options necessary for the task at hand. The more options available to the user, the easier it will be for the user to become confused and select the wrong option (e.g. minimizing the window), leading to confusion and frustration.

To perform the tasks outlined in the IETMs, the users do not need access to the operating system (and probably would be confused if they found themselves there). The "Start bar," therefore, is a large source of confusion, even if it only pops up when the cursor is at the bottom of the screen. It can and should be turned off. The title bar and the controls it contains are also unnecessary. In some IETMs it states the system and procedure being viewed. This is important information, but the title bar is not the best place for it, as putting it there disconnects it from the IETM content it is labeling. A third concern is the “minimize” and “maximize” buttons that also have the potential to lead to confusion. A fourth feature, the “close” button would be better implemented as a "quit" button placed with the other controls within the IETMs. Finally, interface menus often do not fit within the IETM’s interface. They are too small and crowded in their current placement, and for the most part, they contain the functions accessible through buttons. Any functions that are only found within the menus, such as "Help," can be integrated with the rest of the interface as easier to use buttons.

These are major problems, but they may be difficult to fix, as they are due to the nature of the operating system itself. If such changes can be made in any newly developed IETM system, they should be given a high priority.

2. Information Display

The information display area of the interface is divided into two sections, one for the textual steps of the procedure, and one for the accompanying illustrations. They are divided by a vertical rule, which changes position depending upon the size of the illustration. This can be improved by either giving the user control over its placement, or making it immovable. Whatever the case, the buttons that appear on this display are not now and should be coupled to the area they affect.

In the left section, IETMs now often show only one procedural step at a time, giving the user no context within the procedure as a whole. Occasionally a step will have substeps indented beneath it. When this is the case, the current substep has a black rectangle outlining it. The user is expected to continue using a “next” arrow to progress, or may click on the substep. There are much better methods of indicating which step the maintainer is currently using. There is plenty of space on a screen to show more than one step at a time. Also, there could be an indication of which steps have illustrations, requiring the user only to click on the ones he wants to see, rather than having to click between each step.

In some IETMs the illustrations in the right frame are labeled in a poor fashion. For example in one system, a large gray circle represents each label with an arrow extending to the relevant part. When the cursor moves over the circle, the text label appears. The reasoning behind this implementation was to allow more labels to fit on the screen than would be possible otherwise. However, an examination of this IETM did not readily reveal any instances of an illustration within the IETMs with enough labels to require this treatment. Even if some exist, there is a better way of handling the situation. Among the many problems with this roll-over method are: (1) “rollovers” don't work with pen-based input, or any other input that does not use a free roaming cursor; (2) the arrow often gets lost in the diagram, making it hard to find the component or label in question (this is compounded when the arrowhead is larger than its target); (3) when the user magnifies the illustration, the labels are off of the screen, often not able to be seen at the same time as the components they point to. Fourth, arrows point to one specific point on the components they target. Labels should be able to refer to objects in their entirety. Finally, all of the labels link to something when clicked on. Sometimes they link to another diagram, and in these cases, rather than labeling something, they cryptically say something like “diagram.” More often than not, they bring up a new screen that is empty aside from the words in the label itself. This is not helpful to users.

In many IETMs, a three-dimensional arrow labeled “FWD” accompanies each of the illustrations. This arrow is supposed to orient the illustration to the plane, pointing out in which direction the front of the plane is located. A much more intuitive method would be to have an icon of a plane in the proper orientation.

There are numerous changes that could be made to improve information display. The high priority changes needed include: (1) fixing the vertical rule that separates the two areas, (2) displaying multiple steps so the user can get a sense of where they are in the overall task, (unfortunately, this is tied into the step navigation mechanism, which makes for a larger effort to fix), and (3) changing the labeling of the illustrations (this may require manipulation of the content to some extent). Making these changes should enable attainment of the main goal of IETMs, to display content effectively.

3. Buttons

Five critical problems were identified with buttons on the interfaces we were able to examine. First, the button size required in Level IV/V IETMs is too small. Second, their placement often is too close together. Third, some buttons seem to have been scattered across the top of the screen at random, rather than having an organization related to users' mental or task models. Fourth, some of the icons are indecipherable; their symbolism was impossible for both researchers and maintainers to determine initially. Fifth, in some interfaces when the functions that buttons access are unavailable, the buttons disappear from the interface, giving no indication that they exist.

There are two buttons that we term the "Fast Forward" and "Rewind" buttons, as the double arrow icons take their cue from those on a cassette player. We don't know for certain what these buttons do. Our best guess was that they allow the user to jump from one procedure to another in whatever method of serial organization the creators have decided to use (most likely a numerical reference). If this is their purpose, we believe that they are not necessary or useful. If the user's task is to disassemble a component, there doesn't appear to be is any reason he would want to jump to a random procedure from the one he is using. Another possible purpose would be to jump directly to the beginning or end of the procedure. There are more useful ways of implementing such navigation.

Probably the most important controls in the entire interface, the “previous” and “next” buttons deserve a little more prominence within the interface than they are currently given in many IETMs. Warnings, cautions, and alerts show up as buttons after the user has clicked through them. However, there is no visual connection between them. There are better methods of doing this as well.

There are two types of magnification in Level IV IETMs. The user may click one magnification button, which brings up a magnified view in a separate window controlled by moving the cursor over the original illustration. Clicking the other magnification button turns the cursor into a magnifying glass, which can be used to magnify the illustration by clicking on it. The two icons look almost identical. There also are better ways of handling magnification and one solution was tried in this study and is described in Section III.

There are four other buttons in the example procedures we reviewed for which we do not know the functions. One has a drawing of a bolt, one has a poor drawing of a wrench, and the other two, we cannot discern. The use of ambiguous symbols on buttons is a serious problem for users.

Changes to buttons, such as size, placement, and replacement of icons should be trivial to accomplish and will greatly improve usability. Changes requiring greater effort would be an overhaul of the step navigation and a new method for displaying and retrieving warnings, cautions, and notes. Navigation is arguably the most important interface role in IETMs, so this feature should be given highest priority in improving IETMs. Warnings also are a very important part of the content, and should therefore be given a relatively high priority as well.

4. Warnings, Cautions, & Notes

In most current Level IV IETMs warnings, cautions, and notes appear in a window overlaying everything else on the screen. This requires the user to close the window before proceeding. While this practice is in compliance with current military standards, we believe there are better methods, which we addressed in one of the prototypes tested in this study. Current visual representations also contain some Windows “baggage”. For example, the title bar says, "ALERT WINDOW." This is redundant, since directly below that it labels the window as a warning, caution, or note. Also in the title bar is the close box. This is also redundant, since there is an acknowledgement button provided at the bottom of the window (placed there with the expectation that the user will read the contents of the window before closing it). We suggest that the entire title bar be removed from such IETMs. Though it does currently serve one positive purpose, and that is to let the user move the window.

While the use of color is a good idea, its current implementation is lacking. The fully saturated, high contrast, striped borders of caution and warning windows not only do their job of attracting the user's attention, they actually distract users from reading the contents of the window.

From what we see, there appears to be a disconnect between what the client expects (what the military standards setters specified) and what the user needs. It would be desirable to develop a compromise here that works for everyone.

5. Typography

The text within high level IETMs is not benefiting from the typographical evolution of the past hundred years. There are many variables that can make IETMs much easier to read and use. Type size, color, and weight, when used effectively, result in a typographic hierarchy that allows the reader to quickly scan the screen and easily find the information he is looking for. Type size, leading (line spacing), typeface choice, line length, and other formatting considerations can allow the user to read text more easily and quickly. For example, ALL CAPS has been used extensively in IETMs. Text set in all caps is difficult to read due to the lack in variation of letter height that allows readers to subconsciously recognize words. Unfortunately, the developers of the military standards appear to be unaware of a substantial literature (see the annotated bibliography produced by the study team) and set of practices that could greatly improve readability of IETMs. Several of these typographical advances are included in one of the interfaces we tested.

Prioritizing IETM Improvements

Based on the literature review and expertise of the interdisciplinary team working on this research effort, we determined that several improvements could be made and tested. Because of the lengthy list of candidate changes and the limited resources of this ONR study, the team prioritized changes using the following considerations: (1) the expected degree of usability improvement, (2) time and effort required to implement, and (3) the difficulty of identifying and implementing a sound solution. The priorities determined were:

a. Procedure display and navigation are the primary functions of the interface, and would most likely provide the largest degree of usability improvement.

b. The typography, general layout, and button improvement are technically trivial changes with a large return on investment for usability improvement.

c. Windows "baggage" provides a major opportunity for user confusion, but may be the hardest features to change. Thus, these issues were minimally addressed in this effort.

d. Illustration labeling may be easy to design, but time consuming to implement. The improvement in usability would be important. Thus, a limited alternative to the currently available labeling was tested in this effort.

e. Warnings, cautions, and notes may be the most difficult part to design, as the users are at odds with the clients and standard setters on this matter. It would also be time consuming and technically difficult. However, given the potential for improving the user's experience a limited test of an alternative design was done for the mocked-up interface in this study.

III. Study Description

This empirical study began in May 2000 with an extensive literature review (Siegel, J., Hyder, E. and Nawrocki, E., 2000) to determine the state of advanced IETMs for performance aiding and to inform the prototype development and testing of IETMs for F/A-18 maintainers. Major study tasks included:

1. Selection of a candidate F-18 maintenance task for the study.
2. Preparation of field data collection instruments (demographic, self-report and observational questionnaires and checklists).
3. Selection and specification of a set of measures to be used in study.
4. Documentation of field research design.
5. Preparation of navigational and procedural mock-up alternatives.
6. Selection and preparation of hardware.
7. Collection of baseline performance data for the task (without IETMs).
8. Collection of the same F-18 maintainers' task performance using Level 4/5 IETMs including documentation of their navigational and interaction preferences.

For tasks 7 and 8 above, the study team made use of self-report, observational, and think aloud protocol data that was captured along with each participant's actual task performance via video and audio taping. As noted earlier in this report, examples of video clips accompany this report in a CD.

Study procedures and design

The site selected, China Lake Naval Weapons Station afforded us the opportunity to have actual F/A-18 maintainers as study participants. We conducted most of the research during their training days so as to minimize any impact to normal operations. The cooperating officials assured the study team that we would have access to at least six to eight maintainers who varied in their experience levels with aircraft maintenance and experience with F/A-18 aircraft specifically. Also we were afforded opportunities to try out the IETMs both on the flight line (for all baseline instances) and in the hangar (for all "with IETM" trials).

Task selection was done to provide both a practice and actual task that had sufficient complexity to test the effects of providing online documentation that maintainers would truly need to use to complete their activities. Also we selected tasks that would require some mobility so we could compare the impact of having the IETM be very portable in contrast to current carrying of large binders of paper documentation. This study used the paper documentation during the baseline study and then one month later used an actual level IV IETM and a realistic mock-up of alternative navigation and search approaches. The tasks used in both the baseline and "with IETM" parts of the study were: (1) a practice task of several steps in the Inertial Navigation Unit removal task (using paper and online versions of A1-F18AC-730-300, Change 7 - 1 April 1999) and (2) for the actual trial, the Inertial Navigation System (INS) Bit Test (using A1-F18AC-730-200, Change 11). Five participants carried out these tasks on the same F/A-18 model C aircraft for the baseline study and seven participants (including four of the original participants) did so on the same model D aircraft for the "with IETM" condition.

ONR had a unique opportunity to link this study to more applied work since we had access to and selected cutting edge mobile computers developed by IBM (Ditlea, 2000) with VGA quality head-worn displays and Level 4/5 IETMs for F/A-18 aircraft. Originally, we intended to use ViA Inc.'s wearable computers with a visual display produced by MicroOptical Corporation. However, due to difficulties with MicroOptical in shipping working systems within the timeframe of this study, use of the IBM devices became the best option. The technical specification for this wearable computer is: Pentium 233 MMX processor, 64 MB RAM and 680 MB hard drive equivalent to an IBM ThinkPad 560X, but weighing just 400 grams and measuring just 26 x 80 x120 mm. The IBM Watson Center designed head-worn computer display used is a small liquid crystal chip with an image transmitted by a prism and redirected to the user's eye. Due to magnifying optics in the device, it appears to the user that they are reading a full-sized desktop computer screen with VGA resolution. The I/O device used in this study was a dial developed at CMU to enable easy almost hands-free navigation as shown in Figure 1. The users rotated the dial through options for each action to be taken within in interface and then depressed a button on the edge of the dial to select an option. Note that the head-worn display was attached to the maintainers' cranial cap for this study.

The intended design for this evaluation was a repeated measures, within subjects, comparison of performance and preferences. Every effort was made to have as controlled an evaluation effort as possible. Due to operational priorities, just five participants were available for the study in the baseline case. Three additional maintainers were available for the "with IETM" activities and one of the original five participants was unable to take time from his operational duties. A one-month long interval was used between the baseline and "with IETM" treatments to mitigate against any learning effects of participants. Each participant performed the baseline task in late August, 2000 and the "with IETM" task in early October, 2000. The two IETM interfaces tested were varied randomly in the order of use and one-half of each task (practice and INS Bit test) was performed using each interface.

Figure 1: Maintainer wearing vest containing IBM wearable computer with dial for I/O and head-worn display on cranial cap in front of right eye

IETM Interfaces Tested

As noted previously, two different IETM interfaces were tested in this study. Interface A is a Windows/Web browser design that is typical of interfaces in use today, as shown in Figure 2 below. We also chose this interface because it has an appearance similar to the paper documentation. The procedure is listed on the left-hand side and the associated figure is displayed on the right-hand side. Users could change the screen layout by clicking on the appropriate icons in the upper right-hand corner of the display. The viewing options participants had were: (1) one screen with no division, (2) the current two-part display with a vertical division or (3) a two-part display with a horizontal division. Note that this interface uses a smaller font than Interface B and contains some icons and options (e.g., tabs at the top) whose meaning and functions may not be clear to users. For instance, the “Program” tab may not be a topic that aircraft maintainers would expect to encounter and they might not realize that this part of the prototype contains a function to save a session (in case they need to stop before completing a procedure).

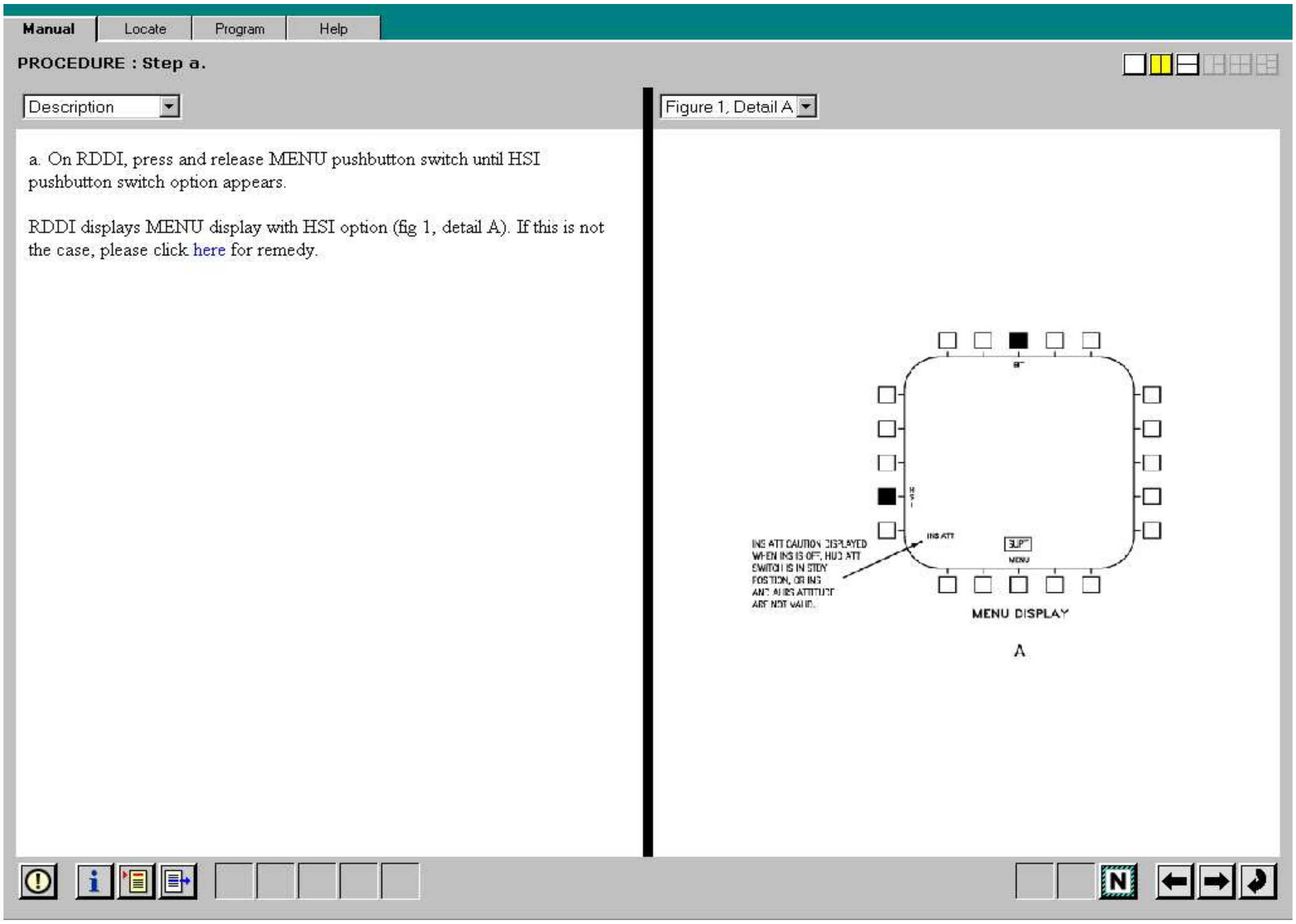

Figure 2: Screen shot of Interface A, Web-browser IETM interface for the Inertial Navigation Bit Test

Interface B was mocked-up for this study and is highly graphical. An example screen is shown in Figure 3. Following is a description of the design solutions incorporated in Interface B to address the insufficiencies of the current IETMs. We note at the outset that some of the decisions for this interface were associated with the fact that it was specifically designed for the CMU dial.

Procedure Display and Navigation

We gave the user context within the procedure by displaying more than one step at a time. First we created three sections representing each section of the procedure. Then we divided each section into "pages." Each page contained the number of steps that could fit on screen at one time.

The navigation frame at the top of the screen displays an icon for each page in the procedure. A user can dial, using the top navigation frame, from one page to the next, changing the set of steps seen in the lower frames. An expert user could perform the entire procedure in this fashion if he did not need the illustrations and other information provided on a step-by-step basis. A novice, or less experienced user, could dial through the lower frames, selecting each step, to get more detailed information about that step (including illustrations and links to other information). The user can immediately see where he is in the procedure by glancing at the navigation screen at the top of the page.

Typography

We used a 13 point sans serif font, Arial , with 20 point leading for several reasons. 1) It is easily readable in the headworn display selected for the testing. 2) This font selection allows a reasonable number of lines of text to fit in the frame. 3) The font accommodates a comfortable line length even with the screen split vertically to provide room to display illustrations.

Background shading is used on alternate steps to visually separate the steps. This is also useful to indicate which icons are associated with which steps, as there are often multiple icons associated with a single step.

Buttons/Icons

Icons were designed to be easily recognizable and meaningful to the intended users. Color is used to indicate which items on the screen can be selected, as well as to separate the icons from the illustrations, which often contain buttons and other controls in the cockpit.

There were two types of icons in this interface. One type of icon was related to the specific procedure being performed (e.g., cautions, illustrations). These icons were a graphical representation of the type of action/information displayed within a circle. The second type of icon indicated links to other procedures and is given a different visual treatment to differentiate this type of icon from the other icons. Icons that indicate links are graphically represented as a notebook, without the surrounding circle.

Because the screen real estate is so small, and the images can be extremely detailed, we provided a method for viewing the image utilizing most of the screen. Selecting and pressing the appropriate icon causes the image frame to expand to the left, covering the text frame, and allowing the user to see more of the image at one time. Magnification and scrolling can also be performed in this mode. Another icon allows the user to go back to the normal view.

Windows-related Features

This issue was easily addressed in our prototype, as our prototyping tool, Macromedia Director, allows the presentation to take over the screen, hiding all Operating system level widgets. There was, therefore, no interface components displayed onscreen other than those that were a part of the IETM prototype.

Alerts - Warnings, cautions, notes

Alerts are attached to individual steps as icons. As the user goes through the procedure step-by-step, when the icon is selected the alert displays in the right hand frame and cannot be skipped. However, the alerts do not obscure the procedure when they are displayed, as they do in other IETMs.

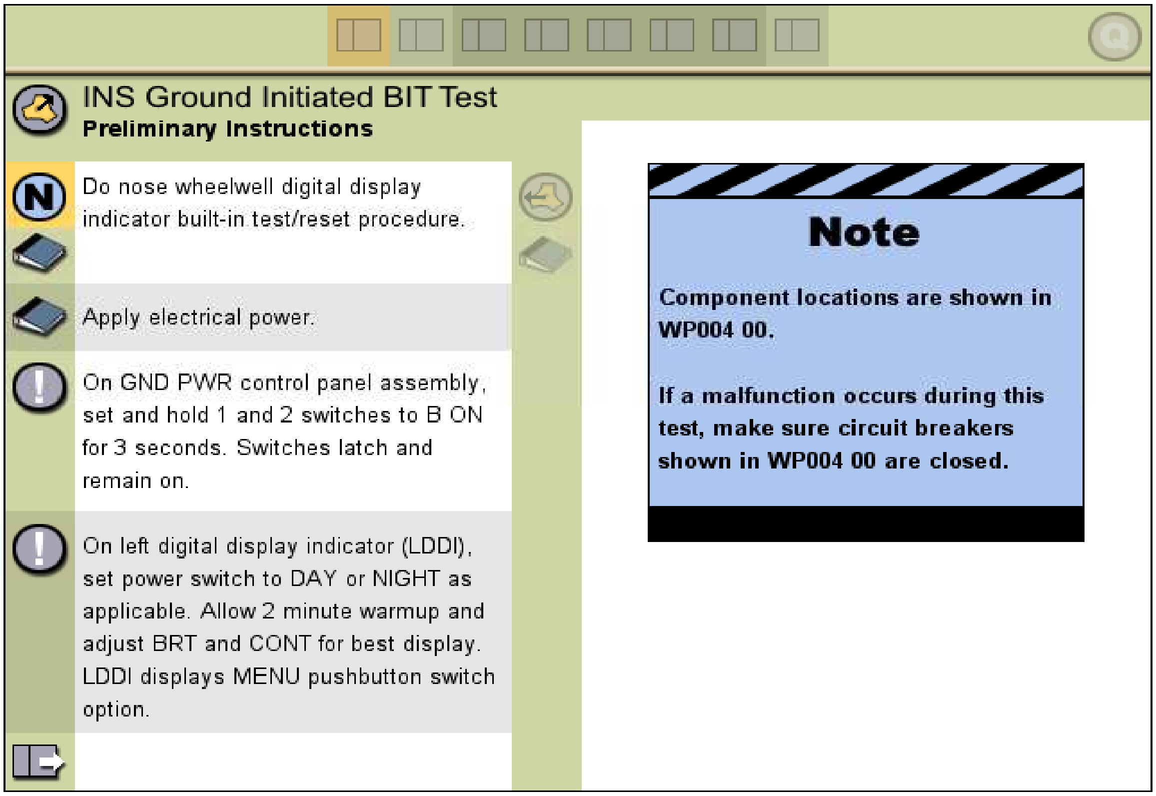

Figure 3: A screen shot of the mocked-up Interface B for the INS Bit Test task.
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IV. Results

In this section, we describe the participants. Then we provide specific instances where the maintainers either succeeded or had major difficulty with particular aspects of the interfaces followed by a summary table of all problems encountered during the IETM trial. Next we summarize their self-report feedback about use of the two IETM interfaces tested in the study. Finally, we summarize the key aspects of the interfaces they preferred associated with their experience levels.

Demographic data

The eight study participants at China Lake, California had characteristics shown in Table 1.

Characteristic	Mean	Minimum	Maximum
Age (years)	27	20	37
Years as F/A-18 maintainer	2 yr. 11 mo.	2 mo.	9 yr. 3 mo.
Years in job at China Lake	1 yr. 6 mo.	2 mo.	5 yr. 2 mo.
Years doing aircraft maintenance	6 yr.	1yr.1mo.	10 yr.

Table 1: Demographic characteristics of study participants (n = 8)

Six of the eight participants received School House and Intermediate or Advanced training for F/A-18 maintenance. One participant was trained to work on F-14 Tomcats and was recently transferred to China Lake to work on F/A-18's but received no formal training for this model aircraft. The remaining participant was trained to work on SH-60 Helicopters and also received no F/A-18 training. Participants were asked to rank their aircraft maintenance skill level (using a scale where 1 = none and 7 = extensive). The average rating from the eight participants was 5.5.

Participants were queried about their previous computer training and none had received any formal training prior to military service. When asked about their "hands-on" computer experience, four indicated they had moderate prior experience and four indicated they had none. Seven of the eight men had some prior experience with IETMs.

Questions regarding vision status of participants revealed the fact that two of the eight had no vision correction, three men had corrective lens for myopia and one was far-sighted. Two men reported other vision problems, e.g., light sensitivity.

Specific interface experiences and problem areas

Three kinds of maintenance experiences with the interfaces are characterized here: (1) navigational challenges, (2) use of magnification, and (3) experience with cautions. There were also several instances of hardware problems. So that readers gain a more concrete sense of the maintainer's view for each of the aspects of the interfaces we tested, we present a brief description of the activity the user was doing and a screen shot of what they saw on the IETM. The accompanying CD contains related video clips with the associated “think aloud” monologue for your information. Then we provide a summary table of all the instances of problems we coded from the video and think aloud data.

Figure 4 illustrates the view each participant began with for the INS Bit Test task while using Interface B. As the participant turned the dial, different steps in the procedure would be highlighted. Navigational problems often were associated with the I/O device For example, an expert maintainer experienced confusion when he turned the dial too quickly “Think I went too fast for the dial. I’m going through a bunch of steps trying to catch up.   I think I went too far. All right. I’ve got it now. Next page…” (P001) Other problems arose from maintainers being unsure about how to go backwards and forwards. To get a clearer sense of the navigational experience of participants using Interface A, please use the accompanying CD and see ONR_7_UseofLink_WUI.mov. In this instance, the participant cannot determine how to get to the term “here” to accomplish a link and asks the experimenter for advice about where to click.

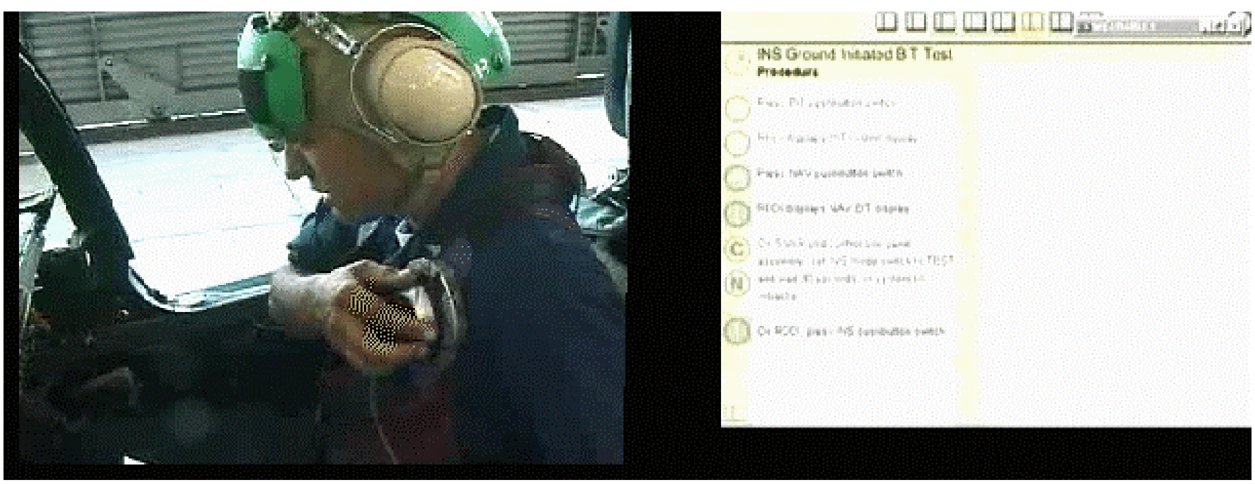

Figure 4: Participant turning dial to navigate through INS Bit Test Task in F/A-18 cockpit (what he sees is Interface B on the right side of this figure).

Magnification was used with each of the interfaces and the users' views of magnified IETMs are shown next in Figures 5 and 6. In general participants did not have difficulty using the magnification features. As noted later in this report, the participants each expressed a desire to have such magnification capabilities in IETMs.

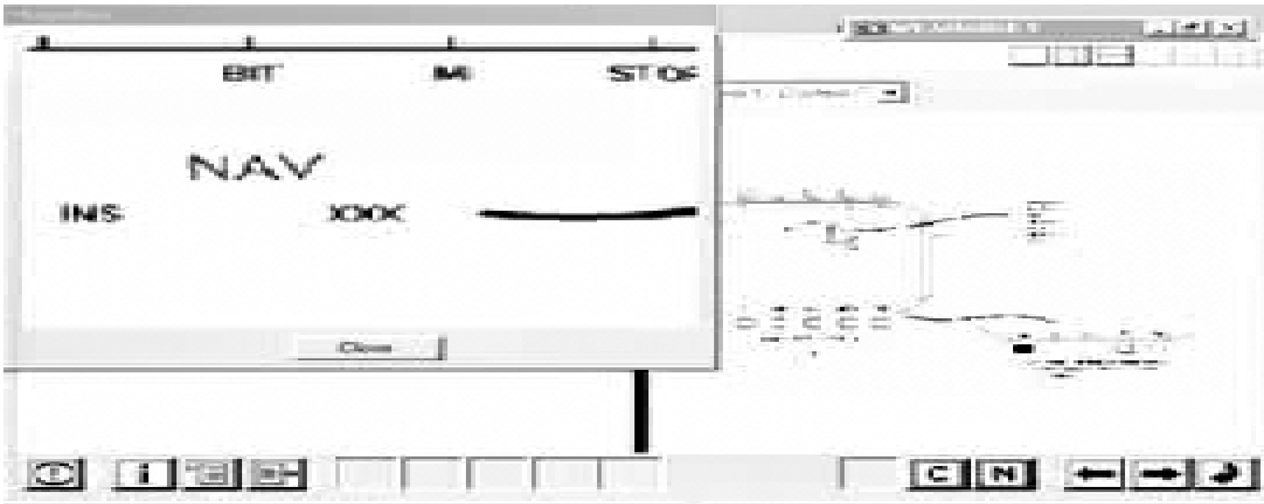

Figure 5: Participant viewing magnified illustration using Interface A.

Using Interface A the participant magnified the illustration and was able to continue the task effectively. We also provide an accompanying video clip of a maintainer using this interface while being mobile (see ONR_3_ Magnification _WUI.mov). He used it so he could locate the correct door to the aircraft to perform the practice task for this study. That participant seemed to have no difficulty with simultaneously walking, talking and seeing the IETM. He did, however, have some difficulty seeing the display without squinting.

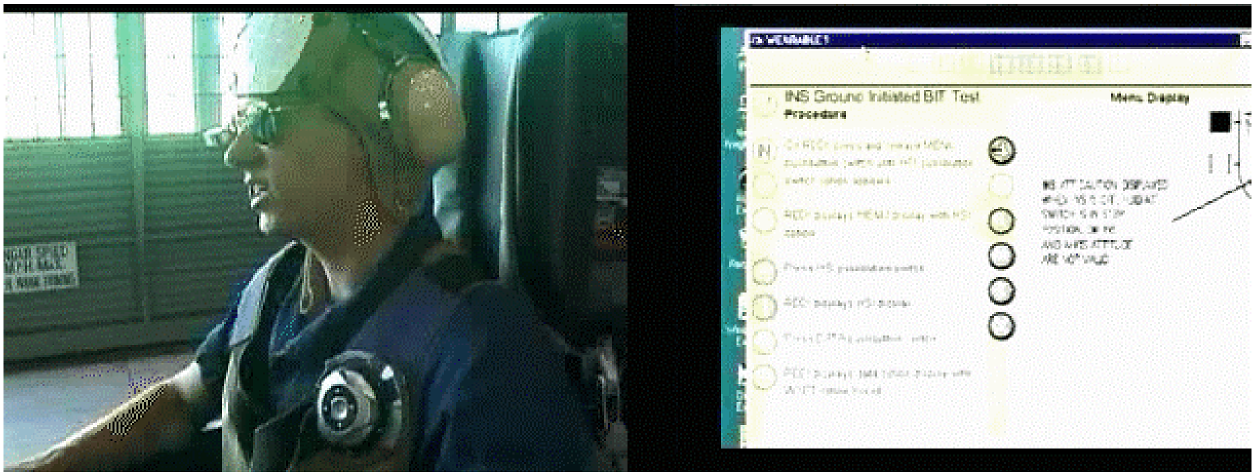

Figure 6: Participant viewing magnified figure using Interface B.

Using Interface B, the participant initially could not see lettering on the IETM illustration. He magnified it to read the accompanying text better and scrolled around to be sure he could see the entire illustration. This enabled him to have confidence that he knew everything he needed to proceed with the task.

Figure 7 shows a participant and the screen he was seeing when reading a caution using Interface A. This caution is in accordance with current IETM standards and effectively blocks the maintainer’s view of anything except the cautionary information. In contrast, in Figure 8 the maintainer is using Interface B where the caution is still very salient, but the associated procedural steps also were visible to the participant. Viewing the associated video clip (see ONR_8_caution_with_note_JUI_mov.) shows that as soon as he takes the required cautionary action, the caution is cleared from the screen enabling him to continue the task. In this instance the IETM design helped him to keep a connection to the overall task structure, but still forced attention to the “Caution”.

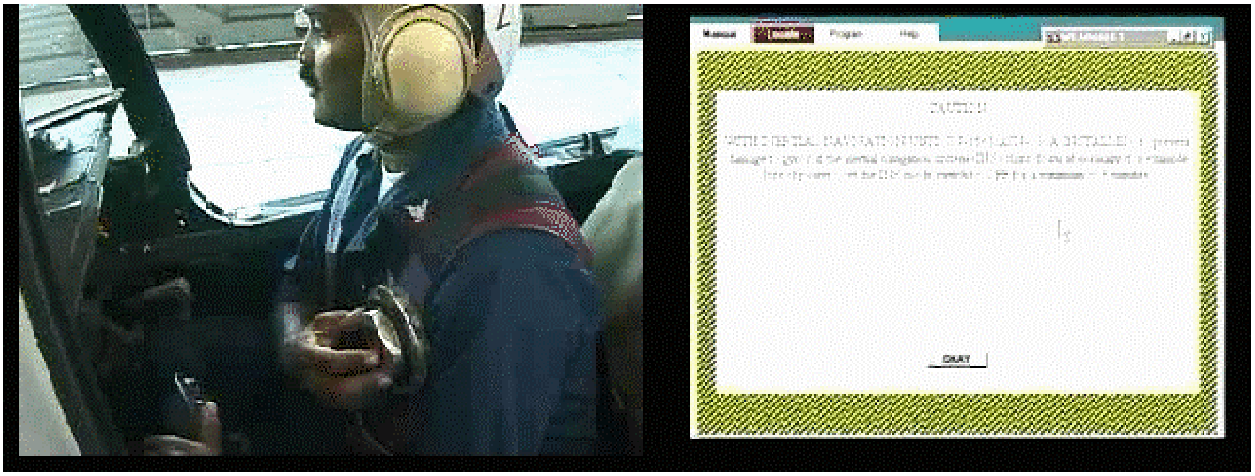

Figure 7: Participant using Interface A to view a caution in the INS Bit Test task

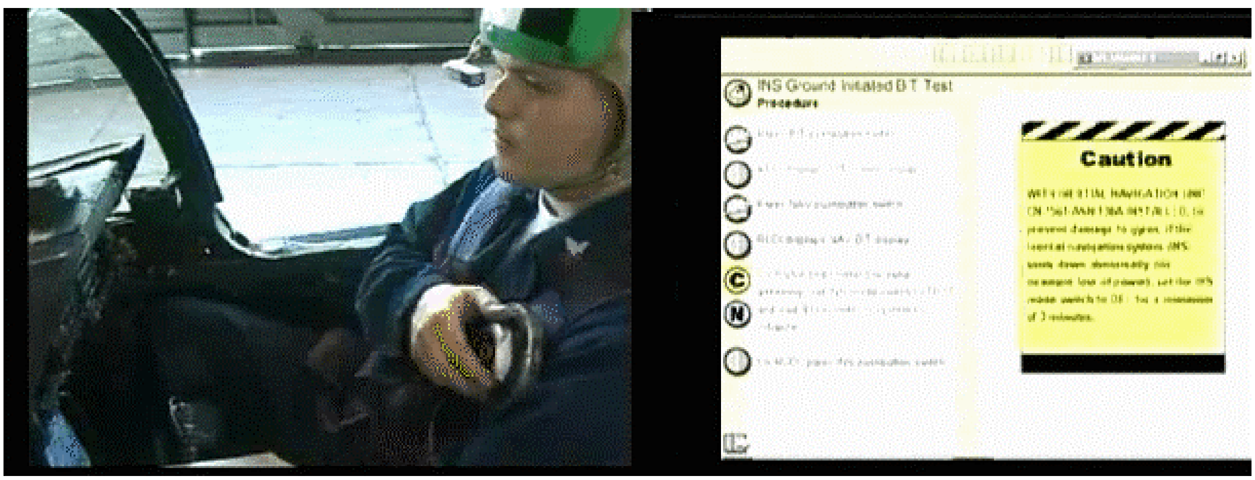

Figure 8: Participant using Interface B to view a caution in the INS Bit Test task

Table 2 shows that participants 004 and 006 had totally different experiences with Interface A and B (no problems with one and many problems with the other). All other participants had a slight difference in performance. However, comparing performance between Interface A and B, there is no significant difference in the total number of problems other participants experienced.   There did appear to be more problems with navigation backward and forward with Interface B. Participants' performance was consistent with their interface preferences that they expressed. These preferences are reported in the next section and discussed later in this report.

Participant Number	001	002	003	004	006	007	008	Totals
Interface A								
Navigation1 (how to do navigating)	1		2		1			**4**
Navigation2 (backward & forward)		2			1			**3**
Navigated incorrectly (i.e., too fast)								**0**
Pauses greater than 30 seconds	1	1			8		1	**11**
Task confusion1 (where in the task)		1					3	**4**
Task confusion2 (what do to)		1	1			2		**4**
Magnification								**0**
Hardware Issues	1		1		1	2	2	**7**
Display on plane differs from IETM								**0**
Total Interface A	**3**	**5**	**4**	**0**	**11**	**4**	**6**	**33**
Interface B								
Navigation1 (how to do navigating)		1		1		1		**3**
Navigation2 (backward & forward)	2	3		5		1	4	**15**
Navigated incorrectly (i.e., too fast)	1	1					1	**3**
Pauses greater than 30 seconds				1		1		**2**
Task confusion1 (where in the task)				1				**1**
Task confusion2 (what do to)	4	2					1	**7**
Magnification			1	3				**4**
Hardware Issues		1		1			1	**3**
Display on plane differs from IETM				1				**1**
Total Interface B	**7**	**8**	**1**	**13**	**0**	**3**	**7**	**39**
Totals Interface A and B	**10**	**13**	**5**	**13**	**11**	**7**	**13**	**72**

Table 2: Summary of participants' problems while using Interfaces A and B (n=7)

Participants' self-reported IETM experiences

Each of seven participants completed a questionnaire immediately after trying out the IETMs and also participated in a videotaped debriefing. All participants were able to complete their work and made mostly positive comments about the IETMs. They also mentioned issues related to use of wearable computers, reinforcing the need for future studies to consider the technology used to deliver IETMs as well as the IETMs themselves. Their responses to the questions are summarized in this section of the report.

Participants' were asked first about correctness of their task performance and then about ease of performing work. They were fairly confident about correctness and indicated that task completion was easy. Their specific responses on these items were:

1. How confident were you that you did the job correctly - average = 4.1
   (Scale used: 1 = not sure, 5 = very sure)
2. How easy was it to complete the task - average = 4.4
   (Scale used: 1 = very difficult, 5 = very easy)

Participants also were asked whether they found the IETMs to be useful and the average response was equal to 4.7 where the scale used was: 1 = not useful at all and 5 = very useful.

We queried participants about any problems or difficulties they experienced and found that most of their reported problems were associated with the wearable system rather than the IETMs. None of the participants indicated they had any difficulties reading the IETMs or talking with others while using the IETMs. Also, none of them reported any problems with finding the information they needed. One participant reported getting confused when he skipped steps he already knew and went just beyond the step he expected to stop at.

Participants were asked to indicate their perceived ease of use or difficulty for each of the two interfaces and their responses are in Table 3 below.

Using IETM Interface A (1=Very Easy; 5=Very Difficult)	Averages
1. Seeing the text in the online application was	1.14
2. Seeing the graphic representations was	1.14
3. Using the index to find information was	1.29
4. Finding the information I needed to link to was	1.71
Using IETM Interface B (1-Very Easy; 5=Very Difficult)	
1. Seeing the text in the online application was	1.43
2. Seeing the graphic representations was	1.14
3. Using the index to find information was	1.71
4. Finding the information I needed to link to was	2.14

Table 3: Ease of use ratings of IETM Interfaces A and B

Participants also had an opportunity to indicate what they liked best and least about the IETM prototypes and their answers are summarized below in Table 4. It is noteworthy that all of the comments about what they liked least were related to the I/O device or the display and not about the IETMs themselves. Also, when asked what they would change they indicated hardware, I/O and display issues.

Participant #	Comment
001	You can use it wherever you want. No need to take out troubleshooting procedures.
002	It is right in front of you and there are no books to worry about.
003	Easy to use.
004	The easy mobility and light weight. Easy to use and carry. Able to move eyepiece away if needed.
006	Don’t have to carry large heavy pubs, and don’t have to worry about whether pubs have been updated or not.
007	Being able to look at text while on the job or in the cockpit.
008	Compactness, immediate availability of information.

Table 4: Likes and dislikes about the IETM prototypes.

The last item from the self-report questionnaire asked whether there was anything else the participants wanted to report and their answers are provided here in Table 5.

Participant #	Comment
004	Graphics very helpful, easy to read and use. Need adapter for when not wearing cranial.
006	Yeah, how soon it’s coming to the fleet.
007	Not all jobs can be explained on screen even with step-by-step procedures. May consider small animated steps when installing/removing certain parts that require “tricks of the trade”

Table 5: Additional comments about IETM prototypes.

All participants indicated they: (1) have a real dislike for the way that cautions and warnings are handled in the IETMs they currently use and preferred both Interface A and B handling compared to their current option; (2) had a strong need for easy use of magnification, and (3) prefer having both the procedural text and graphic information available simultaneously. They noted for example that with current IETMs “ …the only thing that everybody hates is they’ll bring up the note and caution and you have to acknowledge it to go to the next step and everybody is really getting tired of that." (P001)

Comments related to the value of magnification include: "…there's certain times like you know if you need to see something, a clamp, a bolt, a mounting bracket, a pin, whatever, you can look at it to make sure you know and you can move it around to see how it should be fit in there.." (P007) Another maintainer observed that " You look at the graphics and it will show you what it looks like, you can bring it up for more details. It's extremely useful being able to magnify one picture to get more detail out of it". (P004)

Comments about seeing both text and graphics simultaneously on the screen indicated that this was important in getting the task right. For example, in response to the experimenter's question of "Did you find having the images there so you could see the picture with the procedure useful?" Participant 002 stated that "…Yeh, especially when it comes to looking at the DDI because - cause I'm not really the greatest guy but seeing the DDI display - so what I should be on is a good thing. Cause I was actually on the wrong page one time and I had to correct it."

Apart from the features of IETM's that all participants agreed were useful, there were specific aspects of Interfaces A and B that we expected would be preferred and more effective for different users. Analyses of the data that give insights about these issues are described next.

Interface preferences and issues for novice and expert maintainers

We analyzed the self-report comments and debriefing transcripts as well as the video data to determine whether there was any obvious pattern of preference for the two interface options between novice and expert maintainers. Given the small size of the study we would hesitate to generalize. We do provide data about two results here:

(1) the difference in interface preference based on knowledge level and mental models of technical data and (2) the belief that animation or video material demonstrating assembly or disassembly procedures would be critical to IETMs for performance aiding.

Three participants (002, 004, and 008) preferred the Web-manual design - two were novices and the third was an expert, responsible for Quality Assurance for the squadron. The four maintainers who preferred Interface B (P001,003, 006, and 007) were fairly experienced (three had at least five years of experience and one had eight years of experience as aircraft maintainers). The comments of the participants suggest that the novices mental model of the technical information was the paper documentation - so having an online representation that was closest to that familiar information format was easier for them to use. In fact, the one experienced maintainer who preferred the Web-manual commented about his preference for the paper-like view:

> “You get a mind set with the publications where you start memorizing publications and you’re just able to pop it off right there. While the other way you don’t really have an indication of what pub you’re in….So if you’re an inexperienced troubleshooter and you put this thing on, you might not be able to find your way around that very well. The other way, you could take somebody right out of A school that’s got the pub up there.” [he pointed to his head while making this comment](P008)

The participants who preferred Interface B noted the ability to have a sense of the whole task and seemed to value this design feature over the issue of having an online application that was similar to paper documentation. They stated for example “You know the one with the icons…with the yellow background. That one I liked because you had more information on one page. The other way is where you got a small portion.” (P003) Another participant stated

> “I kind of like the second style - the icons. Cause it lets you see all the steps at once and for certain individuals, you know, that are more experienced, you don’t

> need to go step by step by step you can just you know scroll down the screen, instead of having to click, click, click. You can look at and read several steps that are you know inclusive with each other all at once. And then dial to the next step. It helps. it's a little faster. It's almost as fast as flipping pages in a book. That's why a lot of sailors like a book cause you can flip at your own speed. If you need to go slow you can go slow, but if you need to go fast, you can go faster." (P007)

When asking whether there were additional aspects of the IETMs that participants wanted to comment about, we received a detailed suggestion from an experienced maintainer. He believes that IETMs for novices, especially in a reduced workforce scenario should include either video or short animations. He noted that "either a video clip or some sort of animation to show how it slides in and especially certain parts that you don't just - you know, you look at it and o.k. you put it in there - and you're like how do I put it in there? Take an EDU for example, drive wrench, you kinda have to tilt them a little bit, pull and tilt, and stuff like that. But it would definitely take interaction between guys who have done it before and they know the little tricks to getting parts in and out. That would be helpful to the younger sailors - the more inexperienced that don't know how to do it. Cause if it's just them in the pit and they say put this in. Well, easier said then done. That's when you need the other person there….You have to have someone else there."

V. Conclusions and Recommendations

After noting reasons we believe are associated with the results of this study, we make four recommendations for the U.S. Navy (and the overall DoD community) to consider seriously if their objectives for force reduction, adequate operational readiness, and reduced training for military maintainers are to be realized successfully.

Positive responses to mobile IETMs

It appears that overall reaction was very positive to use of mobile IETMs for aircraft maintenance. Of course, maintainers who participated in this study are on the flightline daily trying to use paper documentation and their current PED system for F/A-18 work and are finding this very difficult to do. Many of them also recall the difficulties of doing maintenance with these support materials while on a carrier.

Presented with an alternative that gives each person the support they might need, maintainers found the prototype IETM system we tested very attractive. During the baseline phase of this study, we documented the difficulties of using paper documentation. These difficulties included carrying heavy books to the aircraft, having no place to set the books while working, and having pages flapping in the wind. This latter problem tied up the maintainer's hands while he kept his place in the manual instead of keeping his hands free to do repairs. We also documented the strong positive reactions that maintainers had to the prototype mobile IETM system used in this study. (See video clips showing the same maintainer doing task with paper, with IETM and debriefing on the accompanying CD for an example). During the debriefs the maintainers also commented about problems with current IETMs. For example, one participant stated:

> "Myself, I prefer to use a pub. I prefer to use paper pubs and when they don't have them then I navigate the IETMs. There's a few pubs out there. But unfortunately not enough. IETMs are pretty hard to navigate around. And the biggest, the biggest problem is that you can't get into a specific area. You got to be exact. Sometimes that's kind of hard to do. You don't know the exact word, but you know exactly what you're thinking about. You know what you want to go look for but you get used to calling it another thing and then IETMs refers to as a completely different thing. And it's hard to get to it. Eventually, you do, 20 minutes later. After the missions already lost and the pilots back in the room. I'm just kidding, it's not that bad. But it could use some major improvements. I don't know too many people that are extremely happy the way IETMs navigates. It's a great concept it just needs some work."

The IETM prototypes we tested helped to document problems that maintainers have in a real work setting. Some of these problems are related to differences in the maintainers' experience level. Maintainers' performance and preferences for different interfaces and for different kinds of information were also documented. Given that this is a study of seven people doing one task, we are cautious about generalizing. We are confident, however, given our results and the issues found in the literature that we can make recommendations for improvements in at least four areas. IETM interface and IETMs use with mobile systems require further research via: (1) prototyping and testing IETMs with adaptive options for users of different experience levels; (2) doing a study of multi-user (help desk) prototypes to understand the interplay between the IETM and remote expert help; (3) developing and testing of a larger scale IETM effort, including the whole system, especially, the display and I/O devices to really address the whole list of IETM insufficiencies identified in this study; and (4) prototyping and testing of IETMs to support magnification and tracing and orientation issues for large schematics. We discuss each briefly below.

Adaptive options

Designing and conducting a comparative study of IETM interfaces for novice versus experienced users needs to be done. A key part of such a study would include addition of multi-media support for novices. This seems important since less experienced maintainers appear to need additional support to conduct tasks that may render IETMs whatever the interface to be insufficient. In fact, one of the most experienced maintainers at China Lake suggested during his debriefing session that the Navy should build and test prototypes that add to the IETM. He commented that"

> "…either a video clip or some sort of animation to show how it slides in and especially certain parts that you don't just – you know you look at it and ok you put it in there – and you're like how do I put it in there. Take an EDU for example, you kinda have to tilt them a little bit and stuff like that. But it would definitely take interaction between guys who have done it before and they know the little tricks to getting parts in and out. That would be helpful with the younger sailors – the more inexperienced. Right. That don't know how to do it. Cause if it's just them in the pit and they say put

> this in. Well, easier said than done. That's when you need the other person there. If you have another person there, it's kind of like you don't really need the book, the other things, right in their face. You have someone else there."

Where even the multi-media/enhanced IETMs are insufficient, then there may be a need for human assistance. This issue is addressed next.

Multi-user IETM support systems

To empirically determine the information needs of personnel who have minimal training and are seeking assistance from a remote, more expert maintainer would require task analysis of at least two tasks that the Navy views very critical. The task analysis effort could include documentation of the nature and quality of task dialogue using an extended version of the coding system CMU devised in previous research (supported by DARPA and NSF). Using this coding scheme we could provide DoD with analyses that focus on 1) the number and nature of novice worker's questions, 2) references to objects in the environment, and 3) experts' use of uncommon domain-specific terms. Also, this task analytic effort would provide an information about the circumstances and physical context associated with human interventions. This research could help to inform the design of systems or doctrine to improve performance of novice maintainers.

Interaction of platform and user reactions to IETMs

Two major factors in the use of IETMs for maintainers are the viewability and the hands-free access to information. A systematic heuristic evaluation needs to be conducted in variable physical settings to determine the effects of using small tablet style and head-worn display technologies to view and navigate IETMs. Also, multi-modal interfaces and associated alternative I/O devices need to be tested. Expected outcomes of such an evaluation study would be 1) task analysis and baseline information about use of paper documentation for inspection and repair tasks, and 2) comparative performance and preference data for use of different display technologies that impact the amount of screen real estate, the resolution of information (VGA versus SVGA), the fonts and font sizes, and other relevant factors that might influence usability of IETMs in operational settings. The multi-modal interface development and testing with different I/O devices would provide some factual information about what works and what is feasible now and in the next five years. The results of this study could be used to inform major training and acquisition decisions.

Supporting viewing of large schematic images

Being able to keep track of location and orientation of a wiring diagram or other large schematic image with any resource other than paper is a difficult challenge. Providing viable performance support to novice avionics personnel or generalized maintainers who need this kind of information from online documents is infeasible today. Prototyping and field studies of solutions to rapidly find the means to accomplish this kind of support seems essential at this time.

In sum, while the promise of high level IETMs for Navy maintenance is there, much applied research is needed to realize this promise.

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Appendix I

ONR IETM Study

Initial Questionnaire

August/September, 2000

ParticipantID:______

The results from this study will be used to develop improved Interactive Electronic Technical Manuals (IETMs) to support vehicular maintenance workers in the future.

To help us better interpret your answers to the questions, we need to ask a few questions about your background.

Please answer the questions based on your knowledge and experience from your current and previous training and experience. Please read and answer all of the questions. If you wish to comment on any questions or qualify your answers, please use the space provided.

Your answers will be held in strict confidence. Your name will be used for administrative purposes only.

Thank you for your help.
Dr. Jane Siegel
Human Computer Interaction Institute
School of Computer Science
Carnegie Mellon University
Pittsburgh, Pennsylvania 15213

SECTION I.

1. Name: ________________________ 2. Age: ________ 3. Rank/position: ___________________

4. When did you become an F-18 mechanic? *(Please specify year and month):* __________________

5. How long have you been at your current assignment? *(Please specify in years/months):* ________

6. How long have you been doing aircraft repairs? *(Please specify in years/months):* ___________

SECTION II.

1. Did you receive computer training before taking your current job? *(Please circle):* Yes No
   If yes, please circle all the appropriate categories:

   Operations Programming Word Processing Database Other

   If other, please describe briefly below:

2. If you have prior training on computers, are you familiar with *(Please circle):* Mac PC Other
   If other, please describe briefly below:

3. On a scale of 1 to 7, rate your level of experience using computers *(Please circle):*

1 2 3 4 5 6 7

None Moderate Extensive

4. Did you receive prior, formal aircraft maintenance training in the military? *(Please circle):*

Yes No

If yes, please describe briefly below:

5. Did you receive other formal vehicle maintenance training before military service? *(Please circle):*

Yes No

If yes, please describe briefly below:

6. On a scale of 1 to 7, please rate your skill level for inspecting or repairing aircraft. *(Please circle):*

1 2 3 4 5 6 7

None Moderate Extensive

7. Have you used any military diagnostic tools or online (computerized) IETMs previously? *(Please circle):*

Yes No

If yes, please specify which tool(s) below:

8. Do you have 20/20 vision in both eyes? *(Please circle):* Yes No

If no, *please answer the following:*

8a. Do you wear corrective lenses (eyeglasses or contact lenses) routinely at work?

(Please circle): Yes No

If "yes", please indicate nature of correction, e.g., near-sighted, far-sighted, bifocals, etc. below:

8b. Have you ever had any eye problems, e.g., strain, sensitivity to light, etc.

(Please circle): Yes No

If yes, please explain briefly below:

Thank you for your help.

Appendix 2

ONR IETM Study

Post Questionnaire

10/2000

Participant ID: _______________

Date: _______________________

1. *Please choose the best answer for each of the following*:

A. How sure are you that you completed the task correctly? (1 = Not at all sure and 5 = Very Sure)

B. How easy was it to complete the task? (1 = Very difficult; 5 = Very easy)

C. How useful did you find the Technical Manual(s) in completing the task? (1 = Not at all useful and 5 = Very Useful)

For each item in question 5, please answer the "yes" "no" choice and give a brief explanation for any items when you checked "yes"(Please use the back side of this sheet if you need more space)

1. Did you experience any problems with using the Technical Manuals when:

   5.1: indoors ____ yes ____ no

   5.2: outside ____ yes ____ no

   5.3: wearing safety glasses ____ yes ____ no

   5.4: talking with others ____ yes ____no

   5.5: other ____ yes ____no

- Did you have any difficulties reading the text in the Technical Manuals? _____yes _____no

If yes, please indicate which TO, topic and explain briefly

- Did you get confused about where you were in the Technical Manuals? _____ yes _____ no

If yes, please explain briefly

- Did you have any difficulties finding the information you need? _____ yes _____no

If yes, please explain briefly

For the Baseline study, please stop here

For the online study, please complete:

8. a *Please circle your answer:*

Using web manual	*Very Easy*				*Very Difficult*
1. Seeing the text in the online application was	1	2	3	4	5
2. Seeing the graphic representations was	1	2	3	4	5
3 Using the index to find information was	1	2	3	4	5
4. Finding the information I needed to link to was	2	3	4	5	

8. b *Please circle your answer:*

Using experimental IETM	*Very Easy*				*Very Difficult*
1. Seeing the text in the online application was	1	2	3	4	5
2. Seeing the graphic representations was	1	2	3	4	5
3 Using the index to find information was	1	2	3	4	5
4. Finding the information I needed to link to was	2	3	4	5	

9. Did you have any difficulties using the buttons? ______yes ______ no

If yes, please explain which button(s) and the problems you found:

10. What do you like best about the IETM prototypes?

____

____

____

____

11. What do you like least about the IETM prototypes?

12. What one thing would you change about the IETM prototypes if you could?

13. Is there anything else you would like us to know?

Thank you for your participation in this study.