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A COMPARISON OF PAPER AND COMPUTER PROCEDURES IN A SHUTTLE FLIGHT ENVIRONMENT

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ABSTRACT

The Electronic Procedures Experiment (EPROC) was flown as part of the Human Factors Assessment (HFA) experiment aboard the SpaceHab-1/STS-57 mission. EPROC is concerned with future, longer-duration missions which will increasingly rely on electronic procedures since they are more easily launched, updated inflight, and offer automatic or on-request capabilities not available with paper.

A computer-based task simulating a Space Station Propulsion System task was completed by one crewmember. The crewmember performed the task once using paper and once using computer procedures. A soldering and desoldering task was performed by another crewmember. Soldering was completed with paper procedures and desoldering was completed using computer procedures.

Objective data was collected during each task session from the computer programs, videotapes, and crew notations in the paper and computer procedures. After each task session, subjective data was collected through the use of a computer-based questionnaire program. Resultant recommendations will be made available to future designers of electronic procedures systems for manned-space missions and other related uses.

INTRODUCTION

Experiment Description

The primary concerns of Human Factors engineers at NASA's Human-Computer Interaction Laboratory (HCIL) are the investigation and evaluation of human-machine interfaces unique to spaceflight which affect crew productivity and ultimately mission success. The Human Factors

Assessment (HFA) was an experiment conducted aboard SpaceHab 1/STS-57 by the HCIL. During this mission, HFA personnel evaluated the design and use of electronic procedures (EPROC).

All Shuttle onboard tasks are currently performed using written paper procedures. This represents a large amount of launch weight and valuable stowage space. There are also particular problems with using paper procedures with hands-on tasks. For example, it is cumbersome for crewmembers working in a glovebox to take their hands off the task to turn a page of the procedures or to make an annotation. There are also limitations on the amount of information that can be presented in onboard paper procedures. Electronic, computerized procedures have none of these problems. The amount of information that can be made available and the capabilities that can be provided via computers to improve crewmembers' performance make electronic procedures worthy of investigation.

The goal of the HFA-EPROC experiment was to determine Human Factors requirements for electronic procedures systems in flight environments. Performance measures were taken for the same task using both computer and paper procedures. Advantages and disadvantages of each procedure type were noted. In addition, several automated procedures capabilities were provided to the crewmembers for evaluation. Thus, the investigation could identify the benefits of paper and the potential benefits of computer presentation; rather than solely making a comparison between the two.

The HFA-EPROC experiment consisted of two types of tasks: a computer task and a non-computer task. The computer task consisted of a simulated Space Station Propulsion System task which involved interacting with a graphical interface to configure the system. The task was performed once with computer procedures and once with paper procedures. This type of task was included because future missions will be commanded entirely via graphical software interfaces where crewmembers read on-screen procedures and then configure systems by clicking on icons and soft buttons.

The non-computer task portion of the investigation consisted of a solder/desolder experiment. This portion was performed in conjunction with the SpaceHab Tools and Diagnostic Systems - Solder Equipment (TDS-SE) experiment. The solder portion was completed using paper Flight Data File (FDF) procedures, and the desolder portion was completed using computer procedures. This non-computer task was included to collect information on the use of electronic procedures with a hands-on glovebox task. Because of the hands-intensive nature of the glovebox task, voice input was one of the computer capabilities investigated.

Previous research into paper and computer procedures has been performed in the HCIL at the NASA Johnson Space Center (O'Neal 1992; O'Neal and Manahan 1990; Desaulniers, Gillan, and Rudisill 1989). Results from this research and reviews of relevant literature (Johns 1988; Kelly 1988) provided the basis for the design of the HFA-EPROC experiment.

METHOD

Subjects

Two crewmembers were recruited for the computer task and one crewmember was recruited for the soldering task. Additional subjects and trials were not possible due to mission timeline constraints. During the STS-57 mission, one crewmember was unable to participate due to unexpected mission difficulties; therefore only one crewmember participated in the computer task, plus the crewmember in the soldering task for a total of two subjects.

Apparatus and Materials

A Macintosh Powerbook 170 was used to run the custom-built electronic procedures software. The electronic procedures and the computer task display were created with Supercard. The cursor control device used was a slightly modified version of the standard PowerBook trackball.

The electronic procedures software was custom-built to investigate the usability of the interface. The display was split into halves vertically. The procedures were presented on the left-hand side; the crewmember scrolled through to complete the task. The task was completed on the right side of the display, where a simulation of the Space Station Freedom (SSF) core system Propulsion display was presented. The display was a direct manipulation interface where the user could click on icons representing system objects such as valves or heaters and change the parameters associated with those objects (see Figure 1). The software kept track of task times (between each step in the procedure), the sequence of window openings and closings, and the sequence of button presses.

The non-computer task included the use of a voice input system (Voice Navigator software by Articulate Systems). The system was used solely to move from step to step in the procedure.

Design

The experiment used a simple within-subjects design. The independent variable was Procedure Type (Paper vs. Computer). Dependent variables were: total time on task, time on subsets of tasks, error rate, and subjective ratings.

This basic design was repeated for each task type: Computer and Non-Computer (see Table 1).

	Computer Task	Non-Computer Task
Paper Procedures	crewmember 1	crewmember 2
Computer Procedures	crewmember 1	crewmember 2

Table 1. The experimental design

Subjective ratings were collected via a computerized questionnaire that was presented after the completion of each task. The questionnaire ratings were anchored by using 7 point Likert scales.

Procedure

The crewmembers were trained on their respective tasks during formal familiarization, hands-on, and timeline training sessions. Crewmember 1 also requested and completed several task review sessions prior to the mission.

For both the computer and non-computer tasks, the procedural information available to the crewmember was identical in the paper and computer versions of the procedures. What differed were capabilities to access the information. Table 2 summarizes these differences.

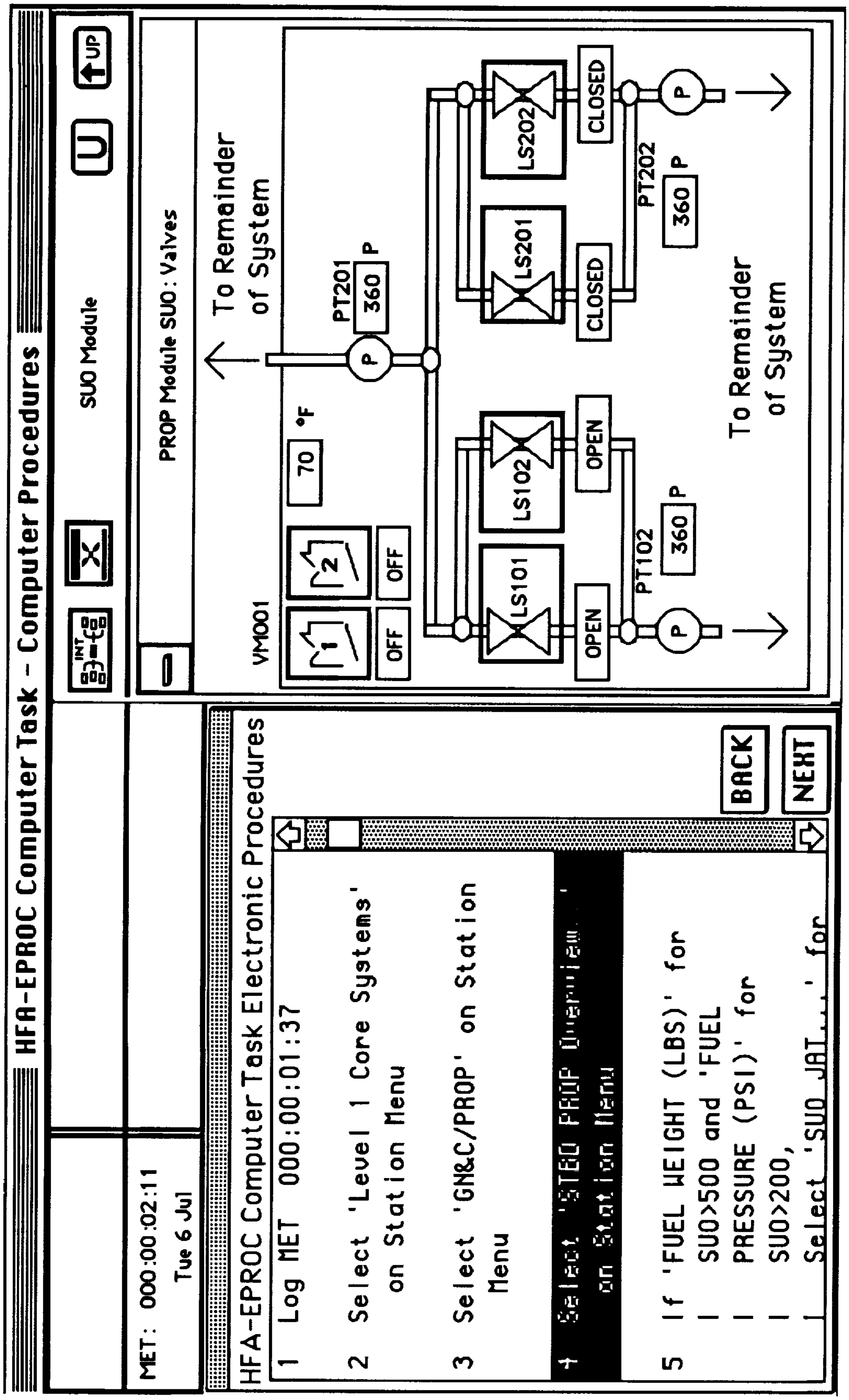

Figure 1. Sample Screen Display for Computer Task, Computer Procedures

Computer Procedures	Paper Procedures
• Immediate access to diagrams, schematics, and malfunction procedures	• Diagrams, schematics, and malfunction procedures in an appendix
• Immediate access to step details	• Step detail information in a separate table
• Notes, Cautions, and Warnings automatically displayed only when relevant	• Notes, Cautions, and Warnings printed along with procedure steps
• Current step highlighted to assist in placekeeping	• Current step not highlighted
• Placekeeping input through use of onscreen buttons	• Placekeeping possible only through manual mark-up of procedures
• Timing information tracked automatically through initial input and use of onscreen buttons	• All timing information tracked manually
• Annotations and comments accepted through available notepad	• Annotations and comments available through pre-defined blank lines or other markings
• Scrolling provided through onscreen buttons and manual use of scroll bars	• No scrolling facilities provided
• Voice input available for increased hands-free procedure operation (non-computer task only)	• No voice input facility provided

Table 2. Comparison of features provided with each procedure type

Computer Task

Crewmember 1 began each computer task session by setting up the computer in the SpaceHab compartment on either the workbench or a computer table. Setup included plugging the computer in, opening it up, and turning it on. The computer was attached to the surface of the table with Velcro. The crewmember stayed in place by using foot restraints.

Crewmember 1 first completed the computer task session while using paper procedures and then completed another computer task session while using computer procedures. Figure 1 shows the display used with computer procedures. Note that for paper procedures the left side of the display remained blank. The right side of the display remained the same for both tasks.

Non-Computer Task

Crewmember 2 began the soldering sessions with the setup of the glovebox apparatus. While performing the computer procedures session, the Powerbook was set up and attached with Velcro to a locker to the crewmember's left in a flat upright position. The Voice Navigator headset was plugged in and the headset was donned.

Crewmember 2 then performed a soldering task session while using the paper procedures. The soldering task consisted of soldering some pre-selected sites on an electronics board while following the procedures. Next, the crewmember completed a desoldering task session on a different electronics board while using the computer procedures. The computer procedures allowed the crewmember to advance to the next step in the procedures via a voice command for "hands-free" operation.

Objective data was gathered for both computer and non-computer task sessions via the computer programs, videotapes, and FDF procedure annotations. This provided baseline data on migrating from paper to computers in space. After each task session, subjective data was gathered through the use of a computer-based questionnaire program, providing data on what to include and what to avoid in the design of future electronic procedures systems.

RESULTS AND DISCUSSION

Computer Task

Due to a late return of flight data, a full data analysis has not yet been completed. Computer data and videotape data have not yet been analyzed; thus the results below include only the completion times and subjective comments. Data from the non-computer task in particular are insufficient for presentation at this time. Thus, only preliminary data from the computer task are presented.

In addition to overall task completion times, task times were broken down into subsets (thirds) in order to get a more granular look at the crewmember's ability to complete the task. The overall task completion time, as well as all of the individual subset completion times were faster for the computer procedures (see Table 3). Formal statistical tests are not appropriate here since the data represent only a few data points from one subject. However, the consistency in trends among each of the sets of completion times indicates that there probably is a real time advantage for the computer procedures.

	Paper	Computer
Overall	17.42	14.83
Subset 1	5.02	3.87
Subset 2	2.98	2.02
Subset 3	9.43	8.23

Table 3. Overall and task subset completion times in minutes.

A full error analysis has not yet been completed. However, a preliminary look at the data indicates no significant errors.

Overall, the computer procedures were rated very favorably in the questionnaire. Regarding the ease of use of the computer procedures interface, the crewmember's comment was "The format of the procedures was very user friendly and resulted in the task being easily performed."

The primary advantage of computer procedures over paper procedures, as identified by the crewmember, was that the current step was highlighted automatically. This released the crewmember from the burden of keeping their place in the procedures. Another comment regarding highlighting was "The procedures were very easy to read. The highlighting assisted tremendously in keeping your place in the procedures. This method assures a 'check and balance' approach to following through required procedures."

One significant improvement that was identified and should be included in any future procedures interface was the capability for the astronauts to be able to move on to the next step via the keyboard or by trackball. The addition of keyboard redundancy allowed the crew to move on to the next step in the procedures while keeping the cursor in the working portion of the display (the task display).

Ultimately, when asked which procedures the crewmember would prefer to use if they were given the choice between paper and computer, the crewmember responded with "I definitely preferred the computer procedures."

The questionnaire data suggested some possible reasons for the quicker task times while using computer procedures. One comment made about using the paper procedures was "The necessity to use paper and pencil to follow through the procedures causes some overhead in zero g. The extra time necessary to clip or tether procedures in the vicinity of the work area and to ensure procedures and writing utensils are not free floating extends the time required to complete the task." Another possible reason for the time difference between computer and paper procedures could be the order of completion. The paper procedures were completed first, therefore the task would have been fresh in the mind of the crewmember as they completed the computer task. However, this effect should have been significantly diminished since the task had been rehearsed many times before the actual mission. Order and practice effects should have been minimal.

CONCLUSIONS

Because Shuttle missions currently use paper procedures, one objective was to establish the paper procedures usability data as a minimum baseline for performance while using computer procedures. Data reviewed thus far would indicate that computer procedures can be used in the future, in place of paper procedures, with no significant loss in productivity.

After the full data analysis has been completed, Human Factors design guidelines will be created, helping designers create more powerful, usable electronic procedures systems. In the future, longer-duration missions will rely increasingly on electronic procedures since they are more easily launched, updated inflight, and offer automatic or on-request capabilities not available with paper.

To facilitate future migration to electronic procedures, performance must at least be equal to performance achieved with paper procedures. This investigation has begun to confirm that electronic procedures are a feasible alternative and can offer many benefits over paper presentation.

REFERENCES

Desaulniers, D. R., Gillan, D. J., and Rudisill, M. (1989). *The Effects of Context in Computer-Based Procedure Displays.* NASA Technical Report. Houston, Texas: Lockheed Engineering and Sciences Company.

Johns, G. J. (1988). *Dynamic Display of Crew Procedures for Space Station, Volume I, Baseline Definition, and Volume II, Functional Requirements.* (MITRE Report No. MTR-88D033). McLean, Virginia: The MITRE Corporation.

Kelly, C. M. (1988). *Conceptual Definition for a Flight Data File Automated Control and Tracking System.* (MITRE Report No. MTR-88D0017). McLean, Virginia: The MITRE Corporation.

O'Neal, M. R. (1992). *The Effects of Format and Contingency on Electronic Procedure Reading Time.* NASA Technical Report number 25705. Houston, Texas: Lockheed Engineering and Sciences Company.

O'Neal, M. R., and Manahan, M. (1990). Spacecraft Crew Procedures: From Paper to Computers. Published in *Proceedings: Fourth Annual Workshop on Space Operations, Applications, and Research (SOAR '90).* NASA Conference Publication 3103, pp. 595-600.

SECTION IV

LIFE SUPPORT

Session L1: SPACE PHYSIOLOGY

Session Chair: Ms. Susan Fortney