A Human Factors Framework for Payload Display Design

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Abstract

During missions to space, one charge of the astronaut crew is to conduct research experiments. These experiments, referred to as payloads, typically are controlled by computers. Crewmembers interact with payload computers by using visual interfaces or displays. To enhance the safety, productivity, and efficiency of crewmember interaction with payload displays, particular attention must be paid to the usability of these displays. Enhancing display usability requires adoption of a design process that incorporates human factors engineering principles at each stage. This paper presents a proposed framework for incorporating human factors engineering principles into the payload display design process.

Introduction

The mission of Marshall Space Flight Center (MSFC) encompasses Space Transportation Systems and Microgravity Research. MSFC is responsible for developing, implementing, and maintaining systems to transport humans into space to conduct various research endeavors. These research endeavors involve interacting with computer controlled experiments using a visual interface. In NASA terminology, crewmembers interact with payloads via a payload display. Optimization of this man-machine interface or display is a problem of critical importance that involves attention to both the physical and psychological aspects of displays. In the past, designers focused on the physical constraints to crewmembers, while giving cursory thought to the psychological aspects of display tasks. However, human factors research indicates that the effect of psychological factors is just as significant as the influence of physical factors. [7]

During the training of crewmembers for space flight, the need for common displays has become apparent. Inadequacies frequently cited by crewmembers include the following: excessive data input requirement, difficult information access, arduous screen navigation, display clutter, familiar keystrokes initiating unfamiliar functions, and illogical hierarchy and organization of screens.

The payload display design (PDD) process is intended to assist in designing visual computer interfaces that appropriately support astronauts' interaction with displays related to payloads that fly on missions and yet provide the needed results for the scientists. For example, a payload display designer should consider the desktop environments that astronauts use most often for their routine computer applications, while also observing human computer interface design principles. Particular attention to astronauts' experiences with and expectations about displays is significant for two reasons. First, missions are time critical, meaning astronauts' tasks during missions are precisely synchronized with a mandated schedule. By minimizing down-time caused by problems like performance errors and preference requirements, time allocated for payload science can be maximized. Second, the cost of training and time allocated for training astronauts to use the various payload displays is limited. Maintaining common usability standards among payload displays will reduce training requirements drastically.

This paper augments the traditional design approach taken in developing payload displays and organizes them into a framework for developing future displays. The proposed framework integrates human factors engineering design techniques at each step. The fundamental principles upon which the framework is based

encompass conventional aspects of human computer interface design, systems design, and human performance. It should be stated that this paper will not attempt to give a detailed discussion of the project's design activity, but rather provide an overview of some design issues from two participants' perspectives.

Traditional PDD Process

Traditionally, display design occurs as a part of human computer interface (HCI) design. In HCI design, the term interface refers to the method of communication between the human user and the computer, including physical and visual components. In this paper, display design refers to design of the visual interface. Several steps typically are involved in designing displays:

1. Develop user scenarios - This initial step involves delineating the tasks the user of the display will need to perform. Because most payloads involve data collection and storage, the display developer obviously should be cognizant of such things as the type of data that must be captured, the format of that data, the amount of data, etc. Also, the display developer should consider the flow of information expected by the user, paying attention to the types of displays commonly used by the crewmembers.

2. Develop a style guide - In addition to using a standard style guide available with commercial off the shelf software like Windows 95 and OSF/ Motif, the developer should design a style guide that is specific to the particular payload display. This may be used as a tool for future display development efforts and as a reference for others who interact with the display.

3. Develop story boards - A story board is a sketched representation of the display. This representation should be as complete as possible, affording clear delineation of process flows, indication of errors, and access to help features.

4. Preliminary design - An early design is formulated. The preliminary design may be in the form of a prototype. In this phase, a configuration concept is established to optimize the basic design approach.

5. Evaluate design options - At this point, the preliminary design is evaluated against the requirements. One approach is to use a checklist to compare the design with the style guide.

6. Evaluate usability - The final step is to evaluate the usability of the interface by having the user interact with the display. In the present system of payload display development, this interaction may not occur until crewmembers are being trained for the specific mission on which the payload will fly. At the training phase, changes are impractical because of schedule and budget constraints.

There are some inherent problems associated with the design approach described above. First, a significant problem is that payload displays often are designed based on the perspective of the developer. This frequently is the case in interface development for environments other than microgravity, where developers design interfaces based on their perceptions rather than on information provided by the user. [4] Second, human factors implications for usability of payload displays is commonly an after thought, given attention only after users indicate problems while interfacing with the display in the training environment. A third problem is that payload displays are developed by a variety of sources, which results in a variety of perspectives on display styles.

Previously, there were no uniform guidelines and standards on design and usability such that each payload display might be significantly different. This disparity led to difficulties in training crewmembers to use displays and increased the training requirements to include aspects of varying displays. In the microgravity environment, the lack of standards led to crewmember performance problems because of poor familiarity with display features or inclusion of display features inconsistent with crewmember expectations. The PDD task will ensure common standards among payload displays.

The next section explains the human factors techniques used in the traditional approach to display design.

Human Factors Engineering in Traditional PDD Process
Human factors techniques in the traditional process encompass function analysis, task analysis, and usability assessments. These are useful tools for the display designer when implemented thoroughly, consistently, and interactively.

Functional Flow Analysis
A function is a broadly defined objective or purpose of a system or subsystem. Functions may be tailored to more narrow emphasis through iterations of the design process. Some examples of functions include monitoring and information transfer. Functional flow analysis involves defining the flow of various objectives through the proposed system. In the case of payload displays, this involves defining the functions of crewmembers and allocating functions based on capabilities and costs. Functional flow analysis, which is the first step in developing user scenarios, gives designers an idea of what the display's purpose will be and what a crewmember's interaction requirements will be.

Task Analysis
A task is a behavior or activity that executes or supports a function. Task analysis involves defining what activities or cognitive processes crewmembers need to perform to achieve the functions of the system. Task analysis, which occurs during the user scenario development step of the traditional design process, is used to create a detailed representation of human interaction with a system. [3] Task analysis is the basic tool in design of displays, development of instruction manuals, preparation of training modules, and design of usability testing. [5]

Usability Assessment
According to the ANSI/HFES Standard, usability may be defined as "the extent to which displays can be used by specified users to implement functions with effectiveness, efficiency, and satisfaction in a specified context of use." There are a number of principles that should be considered in designing displays:

1. Compatibility of system and user's expectations - Whenever possible, the display should match the user's mental model or cognitive picture of the task. The display should use language that matches the user's language rather than the system language.

2. Consistency and standards - Across displays, position actions in the same physical location, include consistent labels, and provide make general processes used to accomplish functions similar to each other.

3. Recognition versus recall - Each aspect of the display should have a distinct appearance that is easily recognized and understood.

4. User control and freedom - The display should be easy to navigate, allowing simple recovery of previous paths and identification of the relationship between actions.

5. Flexibility and efficiency of use - The display should comfortably accommodate both experienced and novice users by allowing shortcuts for efficiency and help support for questions.

6. Error prevention, recognition, diagnosis, and recovery - Probable errors should be anticipated and avoided in the design. The design should provide warning messages, allow multiple attempts to recover from errors, and post error messages and suggest corrective actions in plain language.

7. Aesthetic and minimalistic design - Include only that information necessary and relevant to complete current tasks, and present it in a distinctive manner.

8. Visibility of system status - The display should present timely feedback for all actions to indicate the system status.

The purpose of usability assessment is to determine the degree to which a display meets these principles. Four commonly used evaluation techniques are 1) heuristic evaluation, 2) guidelines, 3) cognitive walkthroughs, and 4) usability testing. [2] Typically occurring as the final step in the design process, usability assessment may occur too late to make meaningful changes in the display.

Rather than applying human factors methods at a few isolated steps of the design process, emphasizing human factors throughout the design process is imperative to achieving a good design. [6] Failure to include human factors considerations in design may result in poor usability, increased human error and poor performance, fatigue, and stress. In critical environments, such as the microgravity conditions under which humans must interact with payload displays, the performance implications are compounded.

Incorporating human factors into the PDD process enhances the usability of the display, in turn leading to better performance of the human component. When provided adequate tools, humans are more productive, efficient, and safe. Because these characteristics are important to overall system performance in space missions, human factors is a vital component of design.

The traditional approach described above can be augmented to better support crewmembers' needs and expectations by integrating more human factors techniques throughout the payload display process rather than at a few isolated steps.

Human Factors Framework for Payload Display Design

Table 1 shows a proposed framework for integrating human factors into the PDD process. The framework modifies a proposed Air Traffic Management systems design framework [3], and points to the systems design process. Traditional and emerging human factors analysis techniques are integrated at each stage of the PDD process. In the framework, the techniques introduced to enhance the traditional process are indicated with arrows.

The systems design process begins as a top-down procedure but is also a bottoms-up synthesis of ideas. The initial step is determination of the objectives and performance specifications. This is followed by various iterations of design, with the process concluding in system test and evaluation. In a similar manner, the proposed framework is iterative in that steps in the framework may be repeated as needed to achieve a good design.

Design Step	Human Factors Activity
Develop user scenarios (Develop concept)	• Task Analysis ⇒ Cognitive Task Analysis ⇒ Error Analysis • Functional Flow Analysis ⇒ Decision Action Diagrams
Develop a style guide	• Refer to Standard Style Guide • Task Analysis • Develop Style Guide for new display ⇒ Decision Action Diagrams
Develop prototypes (Preliminary design)	• Evaluate Function Flow ⇒ Cognitive Task Analysis ⇒ Error Analysis
Evaluate design options (Detailed design)	• Compare against style guide • Task Analysis ⇒ Cognitive Task Analysis ⇒ Simulation (Rapid Prototyping Tool and Questionnaire)
Evaluate usability (Final phase design)	• Usability Assessment • Task Analysis ⇒ Real -time Simulation (Rapid Prototyping Tool and Questionnaire)

Table 1. Proposed framework for integrating human factors engineering into the PDD process.

Note that in Table 1, a variety of human factors techniques such as cognitive task analysis, decision action diagrams, error analysis, user profile development, and real-time simulation are integrated at the appropriate steps throughout the design process. These are meant to augment the traditional approach to display design by extending the attention of designers to reach beyond physical aspects of the display to incorporate cognitive aspects, user expectations, and broader usability focus. The payload display design process shown in Figure 1 indicates the flow of design steps with integration of human factors engineering techniques.

============================== Insert Figure 1 about here ==============================

Cognitive Task Analysis
Cognitive Task Analysis (CTA) is a human factors tool that can be used to define the cognitive or psychological aspects of crewmembers who will interact with payload displays. Because interaction with payload displays is a dynamic activity, it is imperative to capture and accommodate crewmembers' cognitive states and features in designing displays. Designers may use information about crewmembers' mental strategies, search patterns, and information processing and communication characteristics to develop scenarios and to modify design features at the prototyping and design evaluation stages.

Pertinent information obtained from CTA relates to perception and information processing. For instance, situation awareness-oriented design issues and guidelines can be teased out using CTA. A widely accepted definition of situation awareness is "the perception of the elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." [1] How crewmembers achieve situation awareness while interacting with displays impacts design by providing cues to what and how visual information decisions are made. Indeed, a crewmember's mental model or picture of the appearance and functionality of a display will affect performance.

Error Analysis
In addition to mapping the cognitive aspects of humans who interact with displays, it is useful to predict the nature and consequences of performance errors. Error prediction may be qualitative or quantitative. For example, the number of errors of commission and omission are quantitative metrics. Verbal call outs or questionnaire data related to navigation among screens are examples of qualitative information.

Decision Action Diagrams
A Decision Action Diagram (DAD) is similar to a functional flow analysis in that it delineates the flow of crewmember decisions, actions, and operations necessary to meet system requirements. DADs show nominal, alternate, and malfunction flows. For payload displays, DADs resemble flow charts outlining all the decisions and actions relating to interacting with the display, such that display designers may use the DADs to define, organize, and select display objects and aspects of control. To follow human factors principles, DAD formulation at the earliest design stage is imperative. DAD formulation may then be used to support procedures development, which involves delineating for crewmembers instructions on how to use displays.

Real-time Simulation
Real-time simulation aids the payload display designer in two main ways: 1) identification of design deficiencies such as display features and parameters, screen navigation, and information exchange and control; and 2) prediction of error possibilities such as poor support of cognitive functions and expectations. Specifically, the real-time simulation can capture performance and preference data.

Performance data is objective, measuring values like error rate, elapsed time, keystrokes, and errors of omission (frequency of incorrect actions leading to a response other than that intended by the crewmember). Preference data, which are those metrics related to subjective judgments, target opinions about the look and feel of the display. Information about crewmembers' satisfaction and comfort of use are examples of preference data.

A Rapid Prototyping Tool (RPT) can capture performance data. When the RPT is supplemented by questionnaires and verbal call outs, preference data can be captured. A variety of RPTs are available as commercial off the shelf software. Examples of RPT functions are capturing keystrokes, tracking and counting mouse clicks, recording elapsed time, capturing screens, and monitoring controls.

Summary

The PDD task was started to support NASA's commitment to safety, reliability, and low-cost space transportation. The proposed framework will support enhanced usability among payloads by affording developers guidelines for incorporating human factors in the development process. Standardizing displays will 1) cut training costs; 2) reduce the human error rate; 3) enhance safety; and 4) increase the accuracy of space science results. Future work will be to monitor each of these factors and assess the impact of integrating human factors engineering techniques into the display design process. The impact assessment may be measured in terms of a more efficient design process, enhanced teamwork in the design process, and improved usability of displays.

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Develop User Scenarios

- Error Analysis
- Task Analysis
- Decision Action Diagrams
- Functional Flow Analysis
- Cognitive Task Analysis

Develop a Style Guide

- Refer to Standard Style Guide
- Task analysis
- Decision Action Diagrams
- Develop Style Guide for New Display

Develop Prototypes (Preliminary Designs)

- Error Analysis
- Cognitive Task Analysis
- Evaluate Functional Flow

Does current display meet all requirements of Style Guide?

- No → Intergrate Changes Resulting From Data

Evaluate Design Options (Detailed Design)

- Compare Against Style Guide
- Task Analysis
- Simulation (RPT & Questionaire)
- Cognitive Task Analysis

- No → Intergrate Changes Resulting From Data

Intergrate Changes Resulting From Data

Yes →

Evaluate Usability

- Usability Assessment
- Real-Time Simulation (RPT & Ques.)
- Task Analysis

Does current display pass the Crew Consensus Report?

- No
- Yes → Sign and Verify as Flight Hardware