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Human Factors Design Guidelines for Multifunction Displays

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16. Abstract

References related to the design of multifunction displays are summarized into a series of human factors design guidelines. These are presented in a number of sections, which include: general guidelines, the design process, air traffic displays, weather displays, navigation displays, MFD menu organization, automation, individual displays, and general design principles for aircraft displays. Particularly relevant data graphs are included to illustrate some of the recommendations. These sections are followed by samples from the extant body of guidelines and standards.

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TABLE OF CONTENTS

Human Factors Design Guidelines for Multifunction Displays

1. INTRODUCTION

1.1 History of Displays

The current advanced displays seen in a state-of-the-art transport aircraft reflect over a century of development. From the Wright Brothers' piece of string used as a slip indicator to the modern electronic glass cockpits, the cockpit display has been the means of presenting information directly to the pilot. "It is these aircraft displays that are the pilot's window on the world of forces, commands, and information that cannot be seen as naturally occurring visual events or objects" (Stokes & Wickens, 1988).

Serious attention was not given to display development until the advent of the need to fly without visual references and the subsequent "development of a usable gyroscope that could be applied in the form of an artificial horizon" (Hawkins, 1987). From this serious attention, came serious advancements. Later, another technological breakthrough that advanced the state of displays was the rapid development of electronics. This enabled "servo-driven instruments to become possible in the 1950s and then gave the designer the freedom to locate the sensor away from the actual instrument" (Hawkins, 1987).

As digital avionics technology has continued to advance, and as air transport has become a popular means of travel, there has been an increased focus on aviation safety, human factors and display design. As aircraft performance was increasing, more information was made available to the pilot, and both the number and complexity of displays were increasing. "As aircraft grow in complexity and as technology provides the capability of offering more and more information, the pilot's senses can become overloaded with information" (Statler, 1984). The limits of human information processing may be exceeded by the overwhelming increase of warning indicators, status displays, flight path displays, air traffic control data links, meteorological information, navigational information, and communications data. Accordingly, the necessity for well-designed displays is more important now than it ever has been. Also, because of the "tremendous capabilities of the on-board computers to analyze, sort, integrate, and route information from a wide variety of sensors and subsystems, the designers now have fewer constraints and more freedom concerning the location and design of the displays" (Sexton, 1988), as well as opportunities for automation.

1.2 Glass Cockpit

The period from 1970 to the present has been marked by major changes in the appearance of the flight deck due to the introduction of electronic display units (EDU) (Billings 1997). The term "glass cockpit" is synonymous with multi-function displays (MFDs). A typical glass cockpit configuration includes up to 6 electronic display units, backup flight instruments (liquid crystal displays or electromechanical instruments) and a few critical systems indicators on the main instrument panel (Billings, 1997). "Aircraft systems controls are located on the overhead systems panel. A mode control panel, also called a flight control unit, is located centrally on the glare shield below the windscreens. Other flight management system control units and communications controls are located on the pedestal between the pilots, together with power and configuration controls" (Billings, 1997).

1.3 Applications

In the early 1980s, the all-digital AirBus A310 and Boeing 757/767 "introduced cathode ray tube (CRT) flight displays in civil aviation and this marked the watershed in the evolution of the glass cockpit. While the technology employed in the displays was not significantly different, conceptually the A310" (Hawkins, 1987) displays were more advanced than those of the Boeing aircraft. According to Hawkins (1987), "Boeing used an Electronic Attitude Director Indicator (EADI), the display details of which were similar to those of the electromechanical ADI that it replaced." On the other hand, Airbus was able to take advantage of the flexibility of the new displays and elected to introduce a Primary Flight Display (PFD) that integrated the "main airspeed indication, selected altitude and deviation, full flight mode annunciation and various other information" (Hawkins, 1987).

In addition to flight instrument displays, glass cockpit technology also can be applied to the presentation of systems information. This involves engine data as well as other aircraft systems. "The flexibility of this time-sharing form of display enables systems information to be presented only when required, either because of the phase of operation, such as engine starting, or when a system deviates from its normal operating range." (Hawkins, 1987).

Another use of MFD technology is for the flight management system (FMS). The FMS interfaces with the navigation system and is intended to reduce workload, compile complicated lateral and vertical profiles, and supply data for the electronic flight guidance system. In general these systems optimize operating efficiency with a primary aim of reducing fuel costs (Hawkins 1987).

The flexibility of glass cockpit displays has made it possible to provide information when it is needed, in new and different formats, and to modify that information in any way desired by designers to fit any need.

1.4 Multifunction Displays

The multifunction display (MFD) is a display surface which, through hardware or software controlling means, is capable of displaying information from multiple sources and, potentially, in several different reference frames. The device may be capable of either displaying different groups of data (i.e., weather, traffic, or terrain) one at a time or in a combined fashion. In some cases the data may be combined within a single common reference frame or within separate reference frames.

The advances in technology combined with decreases in cost have led to design flexibility of the cockpit displays. As a result, MFDs are becoming increasingly prevalent in aviation. MFDs have been promoted as a means of "layering" information in integrated formats and of using single display surfaces to present large amounts of data. MFDs are capable of presenting data from a number of independent sources, including those from Cockpit Display of Traffic Information (CDTI) systems, enhanced navigational information systems supporting moving maps, weather information sources, Traffic Alert Collision Avoidance Systems (TCAS), and Terrain Avoidance Warning Systems (TAWS). Human factors issues arise when avionics subsystems evolve independently, without consistency in the design of the user interfaces, and are brought together in the cockpit. Cockpit MFDs create the opportunity for a variety of systems to be displayed either simultaneously on adjacent display surfaces, sequentially, in layers on the same display surface, or simultaneously in "windows" on the same display surface. If MFD users are confronted with conflicting, mismatched, and inconsistent display designs, either at the level of display construction and formatting or at the level of data accession method, effective use of the displayed data is likely to be compromised.

1.5 Project Objectives

There are numerous guidelines and standards relating to the basic design of a number of uni-functional displays. However, guidelines are needed for the design, operation, and evaluation of MFDs in the cockpit to promote safety and enhance flight crew performance.

The need for guidance in the design and use of MFDs has been recognized at several levels within the aviation community. Guidelines and standards can have value to numerous participants in this community, including the manufacturers, the regulators, and the consumers. Manufacturers have recently requested guidance from the Aircraft Certification Service of the FAA regarding the design of MFDs, with the intent to provide systems meeting the requirements of certification for use in aircraft. In a parallel development, similar guidance is being sought in the development of guidelines, standards, and certification procedures for the aircraft concepts being developed and tested in the NASA-coordinated Advance General Aviation Transport Experiments. Data also are needed in the development of the MFD concept for the Flight 2000 program and the freeflight environment. In addition, work is proceeding within SAE (the G-10 Subcommittee, Human Factors) to draft an Aerospace Recommended Practice document on the design and use of MFDs. Thus, it is the hope that this report will be useful to both the short- and long-term efforts described above.

1.6 Purpose of Guidelines

The Department of Defense document, Military Standard: Human Engineering Design Criteria Standard for Military Systems, Equipment and Facilities, MIL-STD-1472D (1989), states:

> Visual displays should be used to provide the operator with a clear indication of equipment or system conditions for operation under any eventuality

commensurate with the operational and maintenance philosophy of the system under design.

This statement, while true, is not particularly helpful or useful to a designer or evaluator because the statement is, by need of being overarching, rather vague. Part of the solution to this problem is the use of more detailed and specific design guidelines.

"A large number of interface design guidelines have been developed and can be of great value to the designer. Although guidelines cannot guarantee the success of a design, they may prevent the designers from developing interfaces that will clearly be undesirable" (Liu, 1997). It is important to remember that a display guideline is simply a tool that might be used in a particular stage of the design process.

According to Sanders and McCormick (1993),

> Human Factors is not just applying checklists and guidelines. To be sure, human factors people develop and use checklists and guidelines; however, such aids are only part of the work of human factors. There is not a checklist or guideline in existence today that, if it were applied blindly, would ensure a good human factors product. Trade-offs, considerations of the specific application, and educated opinions are things that cannot be captured by a checklist or guideline but are all important in designing for human use.

"If guidelines are proposed for application in a variety of systems, then they must be written in general terms." (Smith & Mosier, 1984). For example, "a guideline that said 'every display should have a capitalized title centered in the second line' would be too restrictive. Such a guideline would constitute a specific design rule that might be satisfactory in some applications but not in others." (Smith & Mosier, 1984). A more general representation of this design concept could be stated, "every display should be consistently identified in some distinctive way." This guideline would now have a much broader application. Of course, display designers may be disappointed to encounter this guideline if they were expecting a specific rule, only to find general advice instead (Smith & Mosier 1984). Herein lies the paradox: The display designer wants specific rules to apply to a specific design problem. However, specific rules can only be created when one has a full understanding of both the design objectives and constraints within which the design is being created, and these vary widely from application to application. Thus, one is faced with creating either general guidelines which are somewhat applicable to many designs (and require modification for specific application) but are specifically applicable to few as written, or specific guidelines that apply to the design problem at hand, but may not generalize to other design problems.

Guidelines can be thought of as "answers" to display questions. Each display has a unique set of issues and "questions," therefore, no collection of guidelines can exist that will be able to answer each of the unique questions that arise as the designer progresses through the display design process. It is naïve to think that a set of guidelines will result in a well-designed interface. Display design is a creative process and there are no formulas that can insure a successful design (Andre, personal communication, 1998).

To realize "the great value" of guidelines described by Liu (1997), the general guidelines must be translated or converted into specific rules that the designer can follow. So often, designers dismiss the guidelines because they are "too general and of no use." These types of guidelines are purposely general to allow the designer to develop his/her own design rules from these "vague" recommendations.

"Application of guidelines will thus involve questions of how they should be converted into design rules, who should do it, and when" (Smith & Mosier, 1984). At the same time, the appropriateness of generalizing from the many "specific" results obtained in particular environments (typically based on research findings) to the current design environment also must be analyzed.

Design rules should be established "early in the design process, before any actual design of user interface software" (Smith & Mosier, 1984). The design rules should be the joint responsibility of systems analysts assessing design requirements, software designers assessing feasibility, their managers, and potential end-users (Smith & Mosier, 1984).

"Establishment of design rules might begin with review of the guidelines material. Certain guidelines might be discarded as being irrelevant to the particular situation. Other guidelines might be modified" (Smith & Mosier, 1984), and other guidelines may be generalized to the present design situation. All guidelines that are accepted for use should be reworded as necessary to convert them into accepted design rules. In that conversion, some guidelines might be considerably expanded. For example, "a guideline that says displays should be consistently formatted might be converted into a series of eight or ten rules specifying the exact format to be adopted for different elements in a display" (Smith & Mosier, 1984). This process enables specific design rules to be derived from the guidelines material. The development of specific design rules should be performed as an integral part of the design process, serving to focus attention on critical design issues and to establish specific design requirements (Smith & Mosier, 1984).

1.7 Report Organization

This report is organized to be compatible with the information in the previous sections. The first section of the Findings is titled General Guidelines. In this section, the more general design objectives, guidelines, and recommendations are described. From these general guidelines, deletion, acceptance, modification, and expansion will take place to create more specific guidelines (e.g., design rules).

The second section describes the design process recommended for the designers of any display to arrive at their own guidelines or "answers" for their specific display. Pre-existing guidelines are used during various steps of this recommended process.

The third section discusses many of the display design issues and the research and results associated with them.

The fourth section provides samples of existing standards and guidelines for human factors issues in display design from DoD, FAA, NRC, SAE and other sources.

2. METHODS

2.1 Constraints and Assumptions

The selection of literature and the development of the guidelines were constrained for several reasons. First, the primary focus of this effort was concerned with issues unique to multi-function displays, so the majority of the research reports collected dealt with multi-function issues, as opposed to uni-function displays. The scope of this project was not intended to be a restatement of the basic tenets of display design, as represented in many existing handbooks and references on uni-functional displays. However, when these sources contributed useful data or when they addressed the basic display-design/format issues where problems unique to MFDs are encountered, they were included. Some of the general display design guidelines for uni-functional displays are pertinent to the multi-function display issues, and accordingly, are included and discussed within the document.

2.2 Literature Reviewed

Literature related to the design of, or issues associated with, multi-function displays was collected from a variety of sources for review. First were the existing display guideline documents. These were not necessarily from the aviation community but included any appropriate sources from the display design population. Examples include:

- Design Guidelines for User-System Interface Software (Smith & Mosier, 1984)
- Handbook of Human-Computer Interaction (Helander, Landauer, & Prabhu, 1997)
- Designing the User Interface (Shneiderman, 1992)
- Human-Computer Interface Guidelines (Goddard Space Flight Center, 1992)
- Advanced Human-System Interface Design Review Guideline (U.S. Nuclear Regulatory Commission, 1985)

Standards, recommended practices, and standard practice documents also were reviewed. References from these types of sources included:

- Pilot-System Integration (Aerospace Recommended Practice, 1988)
- Transport Category Airplane Electronic Display Systems (FAA Advisory Circular, 1987)
- Human Engineering Design Criteria for Controls and Displays in Aircrew Stations (NATO Standardization Agreement, 1992)
- Operations Concepts for Cockpit Display of Traffic Information Applications (RTCA Special Committee Report, 1998)

Human factors and ergonomic handbooks also were examined. These titles included:

- Handbook of Human Factors and Ergonomics (Salvendy, 1997)
- Human Factors Design Handbook (Woodson, Tillman, & Tillman, 1992)
- Engineering Data Compendium: Human Perception and Performance (Boff & Lincoln, 1988a-i).

Several scientific journals were examined, including:

- Human Factors
- International Journal of Aviation Psychology
- Ergonomics.

Proceedings included those from the
- Human Factors and Ergonomics Society
- International Conference on Human-Computer Interaction in Aeronautics
- Digital Avionics System Conference
- SAE/AIAA World Aviation Congress
- Silicon Valley Ergonomics Conference.

Other sources for information included books on aviation human factors and on general design. These sources included:
- Human Factors in Aviation (Wiener & Nagel, 1988)
- Human Factors in Flight (Hawkins, 1987)
- Aviation Automation (Billings, 1997)
- Design for Success: A Human-Centered Approach to Designing Successful Products and Systems (Rouse, 1991)
- To Engineer is Human: The Role of Failure in Successful Design (Petroski, 1985)
- The Design of Everyday Things (Norman, 1990)

Several seminal references were too lengthy to excerpt in meaningful fashion, containing explicit and detailed data on airborne display applications. These sources are recommended for those readers requiring highly specific detail, and include:
- Analysis of human factors data for electronic flight display systems (Semple, Heapy, Conway & Burnett, 1971)
- Design criteria for airborne map displays (Carel, McGrath, Hershberger, and Herman, 1974)
- Design and use of computer-generated electronic area navigation map displays (Streeter, Weber, and McGrath, 1973)

In addition to these published works, conversations with aviation researchers, commercial pilots, cockpit designers, and consumer product designers were conducted to better understand some of the display design issues and tradeoffs, and equipment functionality and shortcomings of present systems.

3. FINDINGS

3.1 General Guidelines

This section describes the general display guidelines that we encountered. Many of these principles are global in scope and subject to interpretation. These types of guidelines can be converted into more specific guidelines during the design process (see section above on Guidelines under Project Objectives). The sources of these General Guidelines include human factors handbooks, user-interface handbooks, government requirement documents, and software manufacturers' guidelines. A larger sample of existing guidelines published by government or standards-defining organizations is given in Section 4.

Smith and Mosier (1986)

The following principles are described by Smith and Mosier (1986) in their section on Data Display:

Display only and all the necessary data to the user. At any step in the sequence, ensure that whatever data a user needs will be available for display. Tailor the display of the data to user needs, providing only necessary and immediately usable data at any step in the process. The designer of user interface software must employ some method of task analysis to determine a user's detailed information requirements.

1) **Display the data in a usable form.** Do not require a user to transpose, compute, interpolate, or translate displayed data into other units, or refer to documentation to determine the meaning of displayed data.
2) **Display the data consistent with user convention.** If no specific user conventions have been established, adopt some consistent data display standards.
3) **Maintain a consistent display format from one display to another.**
4) **Use consistent, familiar wording** with a minimal use of abbreviations.

Molich and Nielsen (1990)

Molich and Nielsen (1990) presented the following design heuristics concerning user interfaces:

1) Use simple and natural dialogue.
2) Speak the user's language.
3) Minimize the memory load.
4) Be consistent.
5) Provide feedback.
6) Provide clearly marked exits.
7) Prevent errors.
8) Provide good error messages.

Woodson, Tillman, and Tillman (1992)

Woodson, Tillman, and Tillman (1992) present the following "General Guidelines for the Selection and Design of Visual Displays" in their *Human Factors Design Handbook*:

1) **Use the simplest display concept** commensurate with the information transfer needs of the operator or observer. The more complex the display, the more time it takes to read and interpret the information provided by the display, and the more apt the observer or operator is to misinterpret the information or fail to use it correctly. Avoidance of complexity is another way of stating the KISS (Keep It Simple, Stupid) principle that is a cornerstone of applied ergonomics (Salvendy, 1997).
2) **Use the least precise display format** that is commensurate with the readout accuracy actually required and/or the true accuracy that can be generated by the display-generating equipment. Requiring operators to be more precise than necessary only increases their response time, adds to their fatigue or mental stress, and ultimately causes them to make unnecessary errors.
3) **Use the most natural or expected display format** commensurate with the type of information or interpretive response requirements. Unfamiliar formats require additional time to become accustomed to them, and they encourage errors in reading and interpretation as a result of unfamiliarity and interference with habit patterns. When new and unusual formats seem to be needed, consider experimental tests to determine whether such formats are compatible with basic operator capabilities and limitations and/or whether the new format does in fact result in the required performance level.
4) **Use the most effective display technique for the expected viewing environment and operator viewing conditions.**

Optimize the following display features:

- Visibility
- Conspicuousness: Ability to attract attention and distinguishability from background interference and distraction
- Legibility
- Interpretability: Meaningfulness to the intended observer within the environment

Shneiderman (1992)

In *Designing the User Interface*, Shneiderman bases his display guidelines on an earlier work by Smith and Mosier (1984).

1) **Consistency of data displays.** This principle is frequently violated, but it is easy to repair. During the design process, the terminology, formats and so on should all be standardized and controlled.
2) **Efficient information assimilation by the user.** The format should be familiar to the operator and related to the tasks required to be performed with the data.
3) **Minimal memory load on user.** Do not require the user to remember information from one screen for use on another screen. Arrange tasks such that completion occurs with few commands, minimizing the chance of forgetting to perform a step.
4) **Compatibility of data display with data entry.**
5) **Flexibility for user control of data display.** Users can get the information in the form most convenient for the task they are working on.

Lockheed Missiles and Space Company (1981)

Lockheed (1981) details general display design objectives as such:

1) Be consistent in labeling and graphic conventions.
2) Standardize abbreviations.
3) Use consistent format in all displays.
4) Present data only if they assist the operator.
5) Present information graphically, where appropriate, using techniques that relieve the need to read and interpret alphanumeric data.
6) Present digital values only when knowledge of numerical value is actually necessary and useful.
7) Design a display in monochromatic form, using spacing and arrangement for organization, and then judiciously add color where it will aid the operator.
8) Involve operators in the development of new displays and procedures

Helander, Landauer, and Prabhu (1997)

The Handbook of Human-Computer Interaction (Helander, Landauer, & Prabhu, 1997) includes a section that provides guidance in the use of Graphical User Interfaces. The authors state that these recommendations can be generically applied to all GUIs:

1) A GUI design must account for the following characteristics:
   - Metaphor: comprehensible images, concepts, or terms.
   - Mental Model: appropriate organization of data, functions, tasks, and roles.

- Navigation: efficient movement among the data, functions, tasks, and roles via windows, menus, and dialogue boxes.
- Appearance: quality presentation characteristics, or look.
- Interaction: effective input and feedback sequencing.

2) Three key principles guide GUI design:
   - Organization: Provide the designer with a clear and consistent conceptual structure.
   - Economy: Maximize the effectiveness of a minimal set of cues.
   - Communication: Match the presentation to the capabilities of the user.
3) Order and Chaos: Organization lends order to a GUI, making it easier for the user to understand and navigate. Without visual and cognitive organization, the GUI becomes chaotic and, therefore, difficult to learn and use.
4) Consistency: The principle of internal consistency says to observe the same conventions and rules for all elements of the GUI. Without a strong motivating reason, casual differences cause the viewer to work harder to understand the essential message of the display. The GUI should deviate from existing conventions only when doing so provides a clear benefit to the operator. In other words, the GUI should have a good reason for being inconsistent.
5) External Consistency: Leverage Known Design Techniques – The GUI should be designed to match the user's expectations and task experience, rather than force users to understand new principles, tasks, and techniques.
6) GUI Screen Layout: There are three primary means of achieving an organized screen layout:
   - Use an underlying layout grid.
   - Standardize the screen layout.
   - Group related elements.
7) Visual Relationships: Another technique helpful in achieving visual organization is to establish clear relationships by linking related elements and disassociating unrelated elements through their size, shape, color, texture, etc.
8) Navigability: An organized GUI provides an initial focus for the viewer's attention, directs attention to important, secondary, or peripheral items, and assists in navigation.
9) Economy: Economy concerns achieving effects through modest means. Simplicity suggests that including only those elements that are essential for communication. For information intensive situations, the design should be as unobtrusive as possible. Some guidelines regarding economy include the following:
   - Modesty: In general, GUI components should be modest and inconspicuous. Users should be almost unaware of the GUI working to convey meaning.
   - Clarity: Components should be designed with unambiguous meanings.
   - Distinctiveness: Distinguish the important properties of essential elements.
   - Emphasis: In general, make the most important elements salient. De-emphasize non-critical elements, and minimize clutter so that critical information is not hidden.
10) Balanced Communication: To communicate successfully, a GUI designer must balance many factors. Well-designed GUIs achieve this balance through the use of information-oriented, systematic graphic design. This refers to the layout, typography, symbols, color, and other static and dynamic graphics to convey facts, concepts, and emotions.
11) Symbolism: GUI symbolism refers to signs, icons, and symbols that can help to communicate complex information and make the display more appealing. In general keep in mind the following:
    - Use symbols or icons that are clear and unambiguous
    - Use familiar references when possible.
    - Be consistent in size, angles, weights, and visual density of all the signs.
12) Multiple Views: One important technique for improving communication within a GUI is to provide multiple views of the display of complex structures and processes.
13) Advantages of Color: Color, including texture, is a powerful communication tool; so powerful, in fact, that color is easy to misuse or overuse. GUI designers must, therefore, understand color's functions so as to use it with proper skill and sophistication. Some of the most important tasks color can accomplish are these:
    - Emphasize important information
    - Identify subsystems or structures
    - Portray natural objects realistically

- Portray time and progress
- Reduce errors of interpretation
- Add coding dimensions
- Increase clarity or comprehensibility
- Increase believability and appeal

14) In general, similar colors imply a relationship among objects. Therefore, color should be used to group related items, and a consistent color code should be used for screen displays.
15) Color Economy
    - Redundancy - The principle of color economy suggests using a maximum of 5 ± 2 colors where meaning must be remembered. Notice that this maximum is even less than the 7 ±2 which refers to the human cognitive functioning limit with short term memory. If appropriate, use redundant coding based on shape as well as color.
    - Sequencing – To code a large set of colors, use the spectral sequence; red, orange, yellow, green, blue, and violet. Use redundant coding of shape as well as color. This technique aids those with color deficient vision and makes the display more resilient to color distortions caused by ambient light changes.
16) Color Emphasis: Color emphasis suggests using strong contrast in value and chroma to focus the operator's attention on critical information. The use of bright colors for danger signals, attention-getters, reminders, and pointers is entirely appropriate. High-chroma red alerts seem to aid faster response than yellow or yellow-orange if brightness is equal. When too many figures or background fields compete for the viewer's attention, confusion arises, as can happen in the approach to color design that makes displays look appropriate for Las Vegas. Also, older viewers may be less able to distinguish blue from white and blue-green for bluish-white light due to natural aging and change of coloration of the lens of the eye.
17) Color Symbolism: Remember the importance of symbolism in communication: Use color codes that respect existing cultural and professional usage.

Lund (1995)

In a 1995 study, Lund conducted a revealing survey of experienced professionals requesting that they order a collection of general "rules of thumb" based on their relative impact on usability. The following is an ordered listing of the rules that were believed to have the largest impact on usability.

- Know the user, and you are not the user.
- Things that look the same should act the same.
- Everybody makes mistakes, so every mistake should be fixable.
- The information for the decision needs to be there when the decision is needed.
- Error messages should actually mean something to the user, and tell the user how to fix the problem.
- Every action should have a reaction.
- Don't overload the user's buffer.
- Consistency, consistency, consistency.
- Minimize the need for a mighty memory.
- Keep it simple.
- The more you do something, the easier it should be to do.
- The user should always know what is happening.
- The user should control the system. The system shouldn't control the user. The user is the boss, and the system should show it.
- The idea is to empower the user, not speed up the system.
- Eliminate unnecessary decisions, and illuminate the rest.
- If the user made an error, let the user know about it before getting into real trouble.
- The best journey is the one with the fewest steps. Shorten the distance between users and their goals.
- The user should be able to do what the user wants to do.
- Things that look different should act different.
- The user should always know how to find out what to do next.
- Do not let users accidentally cause themselves difficulty.
- Even experts are novices at some point. Provide help.
- Design for regular people and the real world.
- Keep it neat. Keep it organized.
- Provide a way to bail out and start over.
- The fault is not in the user, but in the system.
- If it is not needed, it's not needed.
- Color is information.
- Everything in its place, and a place for everything.

U.S. Nuclear Regulatory Commission (1994)

The U.S. Nuclear Regulatory Commission produced the 1994 document entitled *Advanced Human-System Interface Design Review Guidelines.* Within this document the following general display guidelines were given:

1) Displays should present the simplest information consistent with their function, information irrelevant to the task should not be displayed, and extraneous text and graphics should not be present.
2) All information required by the crewmember during a transaction should be available on the current display.
3) When displays are partitioned into multiple pages, function/task related information items should be displayed together on one page.
4) Information depicted on a display should be grouped according to obvious principles (e.g., task, system, function, sequence) based on crewmember requirements in performance of the ongoing task.
5) Visual or auditory feedback should be provided to indicate that a display input has been registered and that the system response or action is obvious.

FAA (1996)

The Federal Aviation Administration also produced a guide to assist in the design of new systems and equipment, *Human Factors Design Guide for Acquisition of Commercial Off-the-Shelf Subsystems, Non-Developmental Items, and Developmental Systems* (FAA-CT-96-1, 1996). General principles of basic screen design were given as follows:

1) Simplicity – Information should be presented simply and in a well-organized manner. Ways to achieve simplicity include the following:
   - The screen should appear to be orderly and clutter-free.
   - Information should be presented in consistent, predictable locations.
   - The language used should be plain and simple.
   - Interrelationships should be indicated clearly.
2) Logical grouping – Data items on a screen should be grouped on the basis of some logical principle.
3) Minimal movement – Screens should be designed to minimize eye movement.
4) What information to display – The information to be displayed should be prioritized so that the most important or critical information can be displayed all the time, and less important or critical information can be displayed upon s user's request.
5) Minimal information density – The amount of information per unit area should be minimized by presenting only information that is essential to a user at any given time.
6) Screen density – For text displays, the ratio of characters to blank spaces should not exceed 60 percent.
7) Integrated information – If a user needs a variety of data to complete a task, those data should be provided in an integrated display, not partitioned in separate windows or screens.
8) Directly usable form – Information shall be presented to a user in directly usable form; a user shall not have to decode or interpret.
9) Consistent screen structure – Screens throughout a system shall have a consistent structure that is evident to users.
10) Instructions and error messages – Instructions and error messages shall appear in a consistent location on the screen.
11) Maintaining context – An application should provide a means for ensuring that a user maintains an understanding of the context in which a task is being performed. For example, the application might display the results of those previous transactions that affect the current one, or it might display currently available options.
12) Operational mode – If an application provides different operational modes, the current mode shall be continuously indicated to a user.
13) Current context indication – If the consequence of a control entry will differ depending upon the context established by a prior action, a continuous indication of current context should be displayed.
14) Action history – If appropriate, an application shall maintain a summary of the transactions that produced the current context and display it at a user's request. If desirable, an UNDO feature should be linked to each step of the action history.

Microsoft Corporation (1998)

Software manufacturers use principles and guidelines during the design of their products. Following is a sample of Microsoft and IBM's design principles. First off is Microsoft's user-centered design principles as described in Fundamentals of Designing User Interaction: *Design Principles and Methodologies* (1998):

1) User in Control – An important principle of user interface design is that the user should always feel in control of the software, rather than feeling controlled by the software. This principle has a number of implications.
   - The first implication is the operational assumption that the user initiates actions, not the computer or software – the user plays an active, rather than reactive, role. You can use techniques to automate tasks, but implement them in a way that allows the user to chose or control the automation.
   - The second implication is that users, because of their widely varying skills and preferences, must be able to personalize aspects of the interface. The system software provides user access to many of these aspects. Your software should reflect user settings for different system properties, such as color, fonts, or other options.
   - The final implication is that your software should be as interactive and responsive as possible. Avoid modes whenever possible. A mode is a state that excludes interaction or otherwise limits the user to specific interactions. When a mode is the only or the best design alternative — for example, for selecting a particular tool in a drawing program — make certain the mode is obvious, visible, the result of an explicit user choice, and easy to cancel.
2) Directness - Design your software so that users can directly manipulate software representations of information. Visibility of information and choices also reduce the user's mental workload. Users can recognize a command easier than they can recall its syntax. Familiar metaphors provide a direct and intuitive interface to user tasks. By allowing users to transfer their knowledge and experience, metaphors make it easier to predict and learn the behaviors of software-based representations. Metaphors support user recognition rather than recollection. Users remember a meaning associated with a familiar object more easily than they remember the name of a particular command.
3) Consistency – Consistency allows users to transfer existing knowledge to new tasks, learn new things more quickly, and focus more on tasks because they need not spend time trying to remember the differences in interaction. By providing a sense of stability, consistency makes the interface familiar and predictable.
4) Forgiveness – Even within the best designed interface, users will make mistakes. An effective design avoids situations that are likely to result in errors. It also accommodates potential user errors and makes it easy for the user to recover.
5) Feedback – Always provide feedback for a user's actions. Visual and (sometimes) audio cues should be presented with every user interaction to confirm that the software is responding to the user's input and to communicate details that distinguish the nature of the action. Effective feedback is timely and is presented as close to the point of the user's interaction as possible. Even when the computer is processing a particular task, provide the user with information regarding the state of the process and how to cancel that process if that is an option. Nothing is more disconcerting than a "dead" screen that is unresponsive to input. A typical user will tolerate only a few seconds of an unresponsive interface.
6) Aesthetics – The visual design is an important part of a software's interface. Visual attributes provide valuable impressions and communicate important cues to the interaction behavior of particular objects. At the same time, it is important to remember that every visual element that appears on the screen potentially competes for the user's attention. Provide a pleasant environment that clearly contributes to the user's understanding of the information presented.
7) Simplicity – An interface should be simple (not simplistic), easy to learn, and easy to use. It must also provide access to all functionality provided by an application. Maximizing functionality and maintaining simplicity work against each other in the interface. An effective design balances these objectives. One way to support simplicity is to reduce the presentation of information to the minimum required to communicate adequately. Irrelevant information clutters your design, making it difficult for users to easily extract essential information. Another way to design a simple but useful interface is to use natural mappings and semantics. The arrangement and presentation of elements affects their meaning and association.

IBM Corporation (1998)

IBM's design principles for ease of use as described in *What is HCI?* (1998), are as follows:

1) Support: User is in control with proactive assistance. Allow users to be in control of the interface. Don't limit users by artificially restricting their choices.
2) Familiarity: Build on users' prior knowledge. Allow users to build on prior knowledge, especially knowledge gained from experience in the real world. A small amount of knowledge, used consistently throughout an interface, can empower the user to accomplish a large number of tasks. Concepts and techniques can be learned once and then applied in a variety of situations.
3) Simplicity: Don't compromise usability for function. A poorly organized interface cluttered with many advanced functions distracts users from accomplishing their tasks. Keep the interface simple and straightforward.
4) Obviousness: Make objects visible and intuitive. Where you can, use real-world representations in the interface. Real-world representations and natural interactions make the interface more intuitive to learn and use.
5) Encouragement: Make actions predictable and reversible. A user's actions should cause the results the user expects. To meet those expectations, the designer must understand the user's tasks, goals, and mental model. Even seemingly trivial user actions should be reversible.
6) Accessibility: Make all objects accessible at all times. Users should be able to use all of their objects in any sequence and at any time. Avoid the use of modes, those states of the interface in which normally available actions are no longer available or in which an action causes different results than it normally does.
7) Safety: Keep the user out of trouble. Users should be protected from making errors. The burden of keeping the user out of trouble rests on the designer. The interface should provide visual cues, reminders, lists of choices, and other aids. Humans are much better at recognition than recall. Contextual help as well as agents, can provide supplemental assistance. Users should never have to rely on their own memory for something the system already knows.
8) Personalization: Allow users to customize. The interface should be tailored to individual users' needs and desires. In an environment where multiple users are sharing a machine, allow the users to create their own system personality and make it easy to reset the system. In an environment where one user may be using many computers, make personalization information portable so the user can carry that "personality" from one system to another.

3.2 Design Process

Introduction

The general guidelines given in the previous section are used within the context of the user-centered design process. A complete description of the issues, history, and current models of user-centered design processes is outside the scope of this report. The reader is referred to *How to Design Usable Systems* (Gould, Boies, Ukelson, 1997), *Software – User Interface Design* (Liu, 1997), *Handbook of Usability Testing* (Rubin, 1994), *Designing the User Interface* (Shneiderman, 1992), and *Design for Success* (Rouse, 1991) for more in-depth descriptions of the user-centered design process. However, the larger context in which the previously mentioned guidelines are to be used needs to be described as does the process that can help the designer realize their display goals.

The first section brushes the surface of how and why unusable products (including cluttered cockpit displays and complex FMSs) and systems continue to flourish in the field of computer-based products and systems. The second section is a relatively short explanation of the user-centered design process, with many of the references coming from the previously mentioned sources on the process.

Why are so many computer-based products hard to use?

1) **"During product development the emphasis and focus have been on the machine or system, not on the person who is the ultimate end user"** (Rubin, 1994; all following quotes are from this source unless identified as otherwise). There are several reasons for this. First of all, there has been "an underlying assumption that since humans are so flexible and adaptable, it is easier to let them adapt themselves to the machine, rather than vice versa". After all, the thinking goes, the problem can always be solved by training. Secondly, developers, almost invariably comprised of engineers, have been "more comfortable with the seemingly 'black and white,' scientific, concrete issues associated with systems, than with the gray, muddled, ambiguous issues

associated with human beings." Finally, developers have historically "been hired and rewarded for their ability to solve more technical problems, not for their 'human factors' skills."

2) Modern computer-based technology is penetrating new markets and workplaces, where the users are apt to be less familiar with the technology than the designers. The original users of computer-based "products shared similar characteristics" with the developers. Because of this, the developers practiced "next bench" design, a method of designing for the user who is literally sitting one bench away in the development lab. Needless to say, those days are gone. Today's user is no longer even remotely comparable to the designer in skill set, aptitude, expectation, or in almost any attribute that is relevant to the design process.
3) "The design of usable systems is a difficult, unpredictable endeavor, yet many organizations treat it as if it were just 'common sense.'". "The trivializing of usability creates a more dangerous situation than if designers freely admitted that usability was not their area of expertise, and began to look for alternative ways of developing products". Usability principles are not obvious, and there is a "great need for education, assistance, and a systematic approach in applying so-called 'common sense' to the design process." After all, if it were just "common sense", then usable systems and products also would be common.
4) "The design of the user interface and the technical implementation of the user interface are different activities, requiring very different skills". Today, the emphasis and need has shifted more on the design aspect, while many engineers possess the mind set and skill set for tecÈs:hnical implementation.

"It is easy for designers to lose touch with the fact that they are not designing the product, but rather the relationship between the product and the human.." In designing this relationship, "the designers must allow the human to focus on the task at hand, and not on the means with which to do that task."

"What is needed are methods and techniques to help designers change the way they view and design products – methods that work from the outside-in, from the user's needs and abilities to the implementation of the product. The name to this approach is user-centered design."

User-Centered Design

Woodson (1981) defined user-centered design (UCD) as " the practice of designing products so that users can perform required use, operation, service, and supportive tasks with a minimum of stress and maximum of efficiency." UCD involves the design from the human-out and implies that a designer should make the design fit the user. Rubin stated that "UCD represents not only the techniques, processes, methods, and procedures for designing usable products and systems, but just as important, the philosophy that places the user at the center of the process." (Rubin, 1994).

There are many different ways to divide and arrange the design steps within the process. Hewlett Packard's design phase grouping is a typical arrangement.

- Phase 1. Needs Analysis
- Phase 2. Requirement Specification
- Phase 3. Conceptual Design
- Phase 4. Prototype, Development, and Test
- Phase 5. Product Evaluation

Phase 1. Needs Analysis

Gould et al. (1997) call this phase the "Gearing-Up Phase." This is mainly an information gathering phase. The objective is to identify the need for the product by studying user, task, and work environment characteristics. Activities include learning about related systems, familiarizing yourself with standards and guidelines. Identifying and analyzing user tasks. Identifying usability problems on similar or existing products (Gould et al., 1997; Rubin, 1994).

Phase 2. Requirement Specification

Liu (1997) describes the purpose of this phase as being to identify the required functions of the interface and a functional specification of what the interface should do. Gould et al. (1997) emphasize the need to make "preliminary specifications of the user interface, drawing upon existing and leading systems, standards, guidelines, and user interface styles where appropriate." Rubin (1994) also describes the need for a literature review of Human Factors standards, while Smith and Mosier (1984) speak of the need for specific design rules to be established during this phase. This is begun with a review of the general guideline material. Certain guidelines might be discarded as being irrelevant to the particular system. Other guidelines might be modified or expanded upon. The documentation of these guidelines ensues, with periodic reviews and revisions as the design process continues.

Phase 3. Conceptual Design

Hewlett Packard (cited in Rubin, 1994) describes the objective of this phase as the "development of product specifications to meet previously identified requirements and performance objectives." "Alternative interfaces as candidates for final design are generated." (Liu 1997). The integration of Human Factors principles and guidelines takes place in Phase 3 (Rubin, 1994).

Phase 4. Prototype, Development, and Test

This is an iterative phase in which the product is tested with the target user population performing representative tasks. Although many people prefer to "get it right" with the first try, iteration is the norm rather than the exception in design (Liu 1997). Or as Gould et al. (1997) put it, "User testing and iterative design will probably always be necessary to be sure that you did get it right the first time. Even expert bridge players do not always make their bids."

Phase 5. Product Evaluation

This consists of verifying that the product meets the previously defined customer needs, and includes on-site customer evaluations conducted to gain useful data for the next generation products.

The process of user-centered design will help the display designer create a usable system – a system that is easy to learn, easy to use, contains the right functions and the proper displays. Design guidelines themselves will not assure a well-designed system. However, the correct implementation of these guidelines within the user-centered design process will.

3.3 Generalizing From Applied Research

Before the presentation of the various MFD aviation issues and the related research findings are given, the appropriateness and the usefulness of generalizing from past studies to a particular application is discussed. These studies are collectively described as "applied research." The guidelines mentioned in the previous section are not of this "type." Instead, they are "findings that apply or are valid over a wide range of situations" (Chapanis, 1990), and are often derived through what has commonly been termed "basic research."

In his 1990 paper, "Some Generalizations about Generalization," Chapanis defined generalizing as "extrapolating to conditions not identical to those at the time original observations were made – to other groups of people, to other variations of independent or dependent variables, to modifications of variables that were originally held constant, or to other environments."

To take an excerpt from this Chapanis paper, the philosopher David Hume (see Lindsay, 1911) wrote, in *A Treatise on Human Nature*, in 1739:

> Our foregoing method of reasoning will easily convince us, that there can be no demonstrative arguments to prove, that those instances of which we have no experience resemble those of which we have had experience...We suppose, but are never able to prove, that there must be a resemblance betwixt those objects, of which we have had experience, and those which lie beyond the reach of our discovery.

This dismaying point of view has been echoed more recently by experts such as Fromkin and Streufert (1976):

> Although it is important to determine if a relationship is relevant outside the confines of a particular laboratory experiment, generalizations are never logically justified and, to further complicate the issue, there are no objective criteria which yield unequivocal answers to the question of generality.

The belief that findings can be generalized is widely accepted throughout the scientific community. According to Chapanis (1990), "It lies at the heart of all science and governs the way we live." Perhaps the best evidence can be found from the studies of conditioning, behavior modification, and transfer of training. These all tell us that people will react or perform in essentially the same way for a range of similar conditions. A human factors study is basically a simulation in which certain kinds of behavior are observed. It follows, then, that the closer the research situation matches the real one, the more justified we are in generalizing from the empirical findings to what would happen in a real environment (ibid).

The key word is "similarity." The appropriateness in generalizing increases the more closely the simulator or experiment matches the real operating system. Therefore, it is the studies in which the subjects, apparatus, tasks, dependent variables, and the test environment match those of the application as closely as possible that are valued (ibid).

And finally, again from Chapanis:

> It's easy enough to say that research studies should simulate closely the situations to which they are to be extrapolated, but the rule is difficult to apply because we have no way of measuring similarity or of knowing how similar is similar enough. Although attempts have been made to formulate general laws, they are still much too theoretical and apply to too restricted situations to be of use to the human factors practitioner. Under the circumstances, we have to fall back on the experience, sophistication, and good judgement of the investigator. Familiarity with the literature and experience with what works and what does not work are invaluable aids to the investigator in deciding how similar is similar enough.

With this cautionary note, the following sections discuss many of the issues and results of "applied research" work that can be related to MFD design.

4. HUMAN FACTORS GUIDELINES DERIVED FROM RESEARCH

4.1 Air Traffic Displays

Depth Cues as Traffic Display Aids

Background

> "Current aircraft cockpits using multifunction displays present the pilot with two-dimensional representations of the three-dimensional environment. The pilot must take the information from the two-dimensional displays and construct a representational three-dimensional world" (Mazur & Reising, 1990).

Three-dimensional displays have their drawbacks, though. Depth is often difficult to judge, and line-of-sight problems are more likely to exist. Accordingly, many applied research studies have not found that these seemingly more intuitive displays enable superior pilot performance.

With the hopes of alleviating some of the drawbacks of a 3D display, depth cues can be included into the display. These cues can include stereoscopic 3D, familiar size, and aerial perspective.

Stereoscopic 3D is a true binocular cue to depth. It involves "simultaneously viewing the display from two slightly different advantage points and perceptually blending these two distinct perspectives into a unitary mental representation of the external world" (Spain, 1982).

Familiar size is a size cue aid in which the symbol size shrinks to represent objects that are further away.

Aerial perspective incorporates a format in which the symbol becomes grayer and less bright as a function of the object's distance.

General Description

The depth cues help convey spatial location information about other aircraft within the volume of airspace shown on a display. In general, the more depth cues presented to the viewer, the better. The majority of the benefit from the depth cues can be realized with only two cues (Figures 1,2). In addition, there was not a significant difference related to which two of the three depth cues were combined.

Guidelines

Since aerial perspective and size cueing are easier to implement, require less hardware, and would not interfere with any non-3D displays, it is recommended that these two depth cues be used in traffic displays.

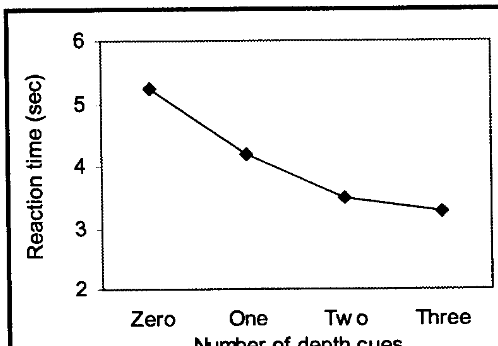

Figure 1. Average reaction time as a function of depth cues.

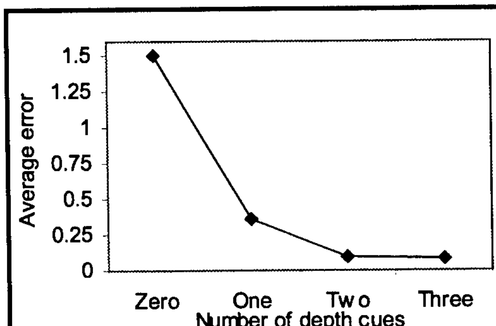

Figure 2. Average error as a function of depth cues.

Constraints or Comments

One of the studies was conducted as a relatively dynamic fighter mission with Air Force personnel (ref. 2).

A visual search task in which the pilots identified the number of aircraft in a particular quadrant was conducted (ref. 1,2).

Key References

1. Mazur, K. & Reising, J. (1990). The Relative Effectiveness of Three Visual Depth Cues in a Dynamic Air Situation Display. In *Proceedings of the Human Factors Society 34th Annual Meeting*, pp. 16-20. Santa Monica, CA: HFS.
2. Zenyuh, C., Reising, J., Walchli, S. & Biera, D. (1988). A Comparison of a Stereographic 3-D Display versus a 2-D Display. In *Proceedings of the Human Factors Society 32nd Annual Meeting*, pp. 53-7. Santa Monica, CA: HFS.

Color-Coded Traffic Information

Background

"The effective use of cockpit displays of traffic information is largely dependent upon the degree to which vertical status and trend information can be presented simply and unambiguously to the pilot" (Beringer et al., 1993).

Beringer goes on to say that the more "traditional use of plan-view displays has been challenged by other representations." Further, although 3D displays may be very useful, "they suffer from potential overlaid symbology causing obscuration or clutter along specific viewing vectors." The article continues that an alternative approach is to "use color coding techniques to represent vertical trend information in a plan-view horizontal situation display."

General Description

Color-coding schemes can facilitate processing of the displayed information and can be an aid in the pilot's cognitive tasks. For instance, color has proved effective where a great deal of information must be presented in a dense format (Kopala, 1979). Maps also benefit from the broad categorization powers of color. Specifically, "color can be used to separate and contrast different elements in a display that cannot be separated properly by space – thereby improving symbol visibility. In this capacity, color serves as an attention cue for the operator." (Stokes & Wickens, 1988). "One of the best demonstrated uses of color coding is for search tasks where color serves as a primary or redundant cue" (Christ, 1975).

For both a 3D and a 2D display of traffic information, the use of color aids in classifying and responding to other aircraft based on their altitude in relation to one's ownship. Research results indicate that color can aid in providing altitude information within a cockpit display of traffic information. Not only are possible threats identified more quickly, but also with fewer errors (Figures 1,2). Guidelines

Incorporate the use of color as a redundant aid in the presentation of altitude data within a traffic display.

If the color coding pertains to altitude, it should depend on the altitude in relation to the ownship - not to the ground.

The color coding should be consistent and should follow current stereotypes (see ref. 1).Constraints

Simplified tasks were carried out to examine the merits of color-coding.

No other displays or color interference from other displays were simulated.

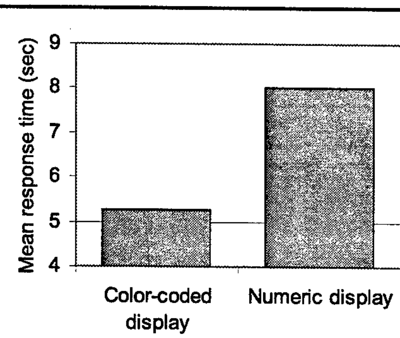

Figure 1. Mean response time for different information coding.

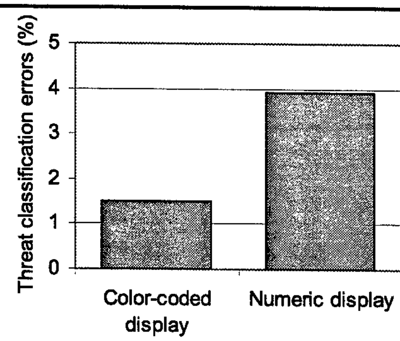

Figure 2. Threat classification errors for different information coding.

Key References

1. Beringer, D., Allen, R., Kozak, K., & Young, G. (1993). Responses of Pilots and Nonpilots to Color-coded Altitude Information. In *Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting*, pp. 84-87. Santa Monica, CA: HFES.
2. Burnett, M. & Barfield, W. (1991). Perspective versus Plan View Air Traffic Control Displays" Survey and Empirical Results. In *Proceedings of the Human Factors Society 35th Annual Meeting*, pp. 87-91. Santa Monica, CA: HFS.
3. M Christ, R. (1975). Review and Analysis of Color Coding Research for Visual Displays. *Human Factors*, 17(6), pp. 542-570.
4. Kopala, C. (1979). The Use of Color-Coded Symbols in a highly Dense Situation Display. In *Proceedings of the Human Factors Society 23rd Annual Meeting*, pp. 397-401. Santa Monica, CA: HFS.
5. Krebs, M.J., Wolf, J.D., and Sandvig, J.H. (1978). Color display design guide. Office of Naval Research: *Final Report ONR-CR213-136-2F.*

4.2 Weather Displays

Rotating Versus Fixed Weather Displays

Background

With the latest generation of supercomputers, newly installed weather observing systems, high speed data communications, and modern computer-generated graphics, it is now possible to present weather forecast information in a format that meets user's needs (U.S. GAO, 1993). The integration and presentation of the weather data raises the question as to what type of display should be used – Rotating or Fixed.

When using a paper map, a user has the option of either orienting the map with the northerly direction upward (north-up, fixed map) or rotating the map to align the direction of travel upwards (track-up, rotating map).

The fixed map requires the user to mentally rotate the map to have the stationary world-referenced frame (WRF) of the map, correspond with the ego-referenced frame (ERF) of the world seen through the cockpit glass.

Since a rotating map always corresponds with the view of the world that the pilot sees, the need for the mental rotation can be eliminated with this type of map. In addition, since the rotating map corresponds to the pilot's view, this is the type of map that follows Roscoe's principle of pictorial realism. That is, that the display should be compatible with the view that the user experiences. On the other hand, the fixed, north-up map provides a constant frame of reference to the user. This enables one to better learn world features and create a mental model of the environment.General Description

Rotating maps are considered superior for navigational tasks, while fixed maps better support tasks that require global situational awareness. These are duties that require the pilot to know where they are "with regards to features and landmarks on the ground and in a much broader volume of airspace" (Wickens, 1992).

Rotating maps led to better performance in navigating around the weather. (See Figures 1 and 2).

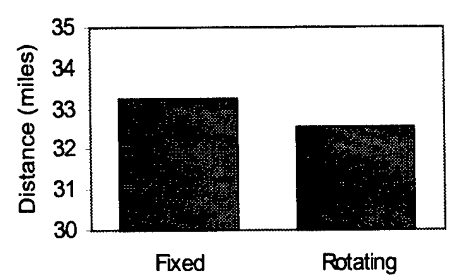

Figure 1. Radial distance traveled for display type.

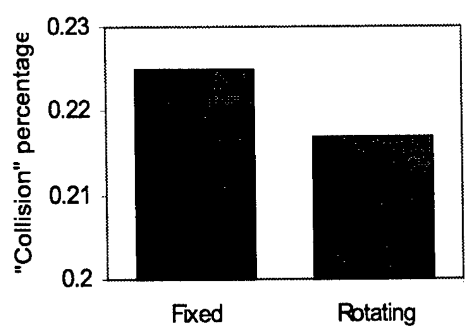

Figure 2. Probability of cloud penetration.

Guidelines

- A rotating, track-up display should be used for the presentation of weather information. Constraints and Comments
- Student pilots were used (ref. 1).
- The sole task was to navigate around a weather problem (ref. 1).
- The 2D display contained 2 views simultaneously – a planar and a profile view (ref. 1).

Key References

1. Boyer, B. & Wickens, C. (1994). *3D Weather Displays for Aircraft Cockpits.* ARL-94-AA/NASA-94-4. NASA Ames Research Center. Moffett Field, CA.
2. Wickens, C. (1992). *Engineering Psychology and Human Performance.* New York: Harper Collins Pub.

4.3 Navigation Displays

Navigation Display Integration

Background

Nowhere has automation been used more effectively than in aircraft navigation displays. Glass cockpit navigation displays are a radical departure from their electromechanical predecessors. All aircraft manufacturers have integrated information formerly presented on electromechanical instruments into a single plan view map display to which has been added other features derived from the flight management system database. Terrain detail, explicit location of ground navigation aids and pilot-constructed waypoints, airport locations, and other data can be portrayed together with the programmed route (Billings, 1997).

- Because of the recent advances in GPS and computing capabilities, issues are now raised concerning exactly how, or even if, terrain, traffic, and weather information should be integrated into the navigation display.General Description
- Surveys of pilots' opinions on what information should be incorporated into the navigation display, and preliminary studies have found that, for example, pilots perform better with traffic and weather displays integrated onto the navigation display (Figures 1, 2).Guidelines
- Primary navigational aids, intersections, and airports should be displayed symbolically with identifying labels for intermediate map scales only.
- Airport control zones, taxiways, and small airports should not be displayed.
- Terrain information should be displayed automatically if an aircraft was below the minimum safe altitude (MSA), and should also be available at pilot request.
- The majority of airline pilots did not want weather information included on CDTI (Hart & Loomis, 1980). Another survey, however, suggested that the pilots do want weather integrated on the navigation display (Hart & Loomis, 1980). Both groups agreed that if weather is incorporated into another display, it should be initiated by the pilots rather than occurring automatically.
- The display of other aircraft should be limited to those nearest the ownship. One survey suggested displaying only those aircraft that are within ± 2000 ft.
- Commercial pilots also wanted to know whether another aircraft was flying under visual or instrument flight rules to be displayed digitally or coded into the symbol, and should only be displayed at the pilots request.

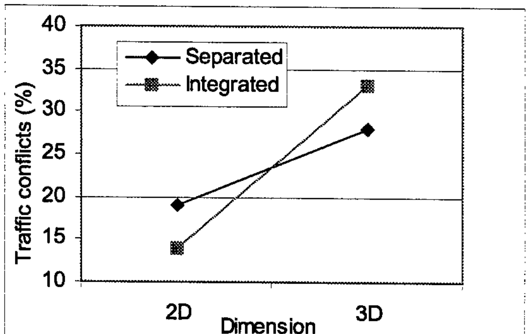

Figure 1. Traffic conflicts as a function of display dimension and integration.

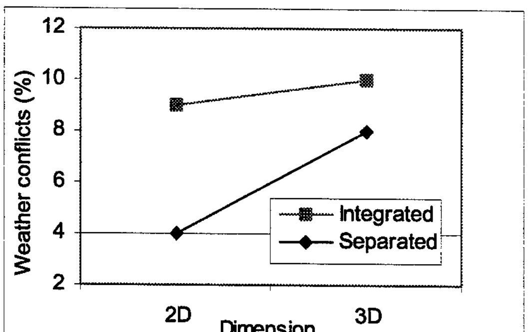

Figure 2. Weather conflicts as a function of display dimension and integration.

- A coplanar navigation display is recommended that includes both weather and traffic information.
- The capability to turn on or off the overlaid terrain, traffic, or weather data is recommended. Except for the instances when minimum safe altitudes or distances are violated, the displays should not be introduced or removed automatically.

Constraints

- Little research has been done to determine what information should be displayed in conjunction with the navigation display.

Key References

1. Hart, S. & Loomis, L. (1980). Evaluation of the potential format and content of a cockpit display of traffic information. *Human Factors*, 22(5), pp. 591-604.
2. O'Brien, J. & Wickens, C. (1997). *Cockpit displays of traffic and weather information: Effects of dimension and data base integration.* Technical Report ARL-97-3/NASA-97-1. Aviation Research Laboratory. University of Illinois at Urbana-Champaign.

Rotating versus Fixed Navigation Displays

Background

When using a paper map, a user has the option of either orienting the map with the northerly direction upwards (north-up, fixed map) or rotating the map in such a way as to constantly align the direction of travel upwards (track-up, rotating map). Similarly, an electronic navigational map can be displayed either way.

The rotating map would seem to enable superior pilot performance by presenting an inside-out or ego-centered representation of the environment. This design follows the principle of pictorial realism in that it represents an "out the window" view. However, there is some reason to believe that a track-up map may violate the pilot's mental model of the motion relationship, in which it is the aircraft not the environment that is moving.

General Description

Different tasks require different map orientations. North-up maps have been found superior in landmark searching tasks, and for pilot communication with other aircraft. Both of these tasks are best served with a consistent location of landmarks (a stationary world), that is afforded by the north-up map. Wickens (1992) has described these types of tasks as "global situation awareness" tasks. These are duties that require aviators to know where they are with regard to features and landmarks on the ground and in a much broader volume of airspace.

On the other hand, local guidance tasks seem to be performed best with the track-up display. These are tasks in which the pilot needs to know when to climb, descend, accelerate, or decelerate to follow the appropriate path.

A track-up map is the better choice for navigation displays. Indeed studies have shown that, not only do pilots prefer the track-up navigation display, but that they also perform better with it (Figure 1).

Guidelines

- The navigation display should be presented in a rotating, track-up format.

Constraints and Comments

- The empirical results were somewhat mixed (Refs. 1, 2).
- The consistency between displays (i.e. whether the displays are all one type or if there is a mixture) is important (ref. 1).
- Widely varying navigational screens were used in the three referenced studies.

Key References

1. Andre, A., Wickens, C., Moorman, L., & Boschelli, M. (1991). Display Formatting Techniques for Improving Situation Awareness in the Aircraft Cockpit. *The International Journal of Aviation Psychology*, 1(3), pp. 205-218.

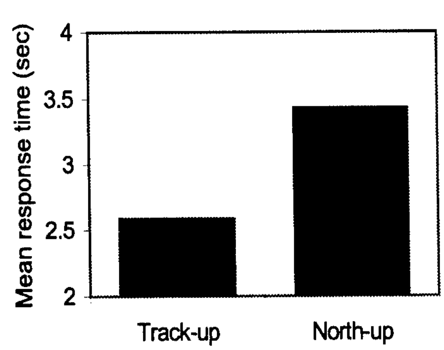

Figure 1. Mean navigation response time as a function of map type.

2. Aretz, A.J. (1991). The Design of Electronic Map Displays. *Human Factors*, 33(1), pp. 85-101.
3. Harwood, K. & Wickens, C. (1991). Frames of Reference for Helicopter Electronic Maps: The Relevance of Spatial Cognition and Componential Analysis. *The International Journal of Aviation Psychology*, 1(1), pp. 5-23.

3D Display Elevation Angle

Background

With the recent advances in technology, the utilization of 3D displays in the cockpit has received some attention in the research literature. Many applied research studies have been conducted to access the worth of the various designs and ultimately, make design recommendations.

One aspect of the 3D display that has not received much attention is the question of the optimum elevation angle for the 3D display. Differences in elevation between a map and a pilot's forward field of view (FFOV) are known to effect the efficiency in 3-dimensional image comparisons. "Such would be the case when flying with a 90 degree (top-down) map and an FFOV that is inherently 3-dimensional and something less than 90 degrees." (Hickox & Wickens, 1997).

Part of the cost associated with a 3D display is the required mental rotation that the viewer must complete to have the display "line up" with the view of the world available to them out the window. Studies have found that the response time costs associated with elevation angle is not a linear effect (Hickox & Wickens, 1997). This result is a departure from the linear relationship normally associated with 2D mental rotation.

General Description

Past research has not developed a formula that can adequately predict pilot response times based on the angular disparity between the FFOV and the Map display. The Hickox and Wickens study (ref. 3) predicts response time not as a function of the difference between the map and FFOV, but between the absolute value of the sine difference of the map and FFOV. This response time data, combined with the accuracy data and the Yeh and Silverstein (1992) data, suggest that the optimal elevation angle for the map display is 45 degrees.

Guidelines

- If a 3D perspective display map is to be used, the elevation angle should be close to 45 degrees.

Constraints

- An image comparison test was conducted (ref. 3).
- There was only a small decrease in performance for angles of elevation slightly lower than 45 degrees (ref 3).

Key References

1. Aretz, A., & Wickens, C. (1992). The mental rotation of map displays. *Human Performance*, 5(4) pp. 3-28.
2. Eley, M. (1988). Determining the shapes of land surfaces from topographic maps. *Ergonomics*, 31, pp. 355-76.
3. Hickox, J. & Wickens, C. (1997). 3-D Electronic Maps, Design Implications for the Effects of Elevation Angle Disparity, Complexity, and Feature Type. In *Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting*, pp. 23-27. Santa Monica, CA: HFES.
4. Yeh, Y-Y, & Silverstein, L. (1992). Spatial judgements with monoscopic and stereoscopic presentation of perspective displays. *Human Factors*, 34, pp. 583-600.

Taxiway navigation maps: HUD and 3D vs. 2D

Background

Major automation projects are currently underway to increase the efficiency and safety of airborne traffic. Improvements have already been realized in supporting low-visibility landings as a result of the technological improvements (Lasswell & Wickens, 1995). However, these improvements will be lost without similar improvements in ground traffic flow. "A pilot who successfully completes a mission and lands in zero-visibility conditions will be faced with the daunting task of rolling off the runway and maneuvering to the terminal with little or no visual cues" (Lasswell & Wickens, 1995). Recent mishaps involving runway deviations and "ground traffic collisions further highlight the need for improved methods" (Lasswell & Wickens, 1995).

Regardless of the technology to be used in supporting the pilot, a central issue still concerns the interface between the technology and the user. "The display must enhance the pilot's situation awareness, while minimally interfering with the taxiing task" (Lasswell & Wickens, 1995). The question of whether to present the map and the route guidance in a head-up or head-down fashion, and in a 3-D or 2-D view is directly related to this issue.

Presenting information head-up provides the potential benefits of reducing the scanning distance between the display and the scene out the window, and reducing the accommodation changes necessary to switch between the two domains. These advantages are countered by the problems of clutter resulting from the overlapping images and the problem of cognitive capture. Placing information within an operator's forward field of view may create an involuntary attraction of attention to the HUD, even when there is no need for it

Similarly, the effectiveness of 3-D displays may actually suffer as a result of their more realistic presentation of the environment. For instance, 3-D displays introduce a degree of ambiguity regarding the precise location of points along the line of sight, and limitations arise from the limited field of view allowed by an egocentric display.General Description

The use of a HUD is advantageous for tracking tasks. Also, average taxi speed was increased when information was presented in the head-up location (Figure 1).

It appears that superimposing the route guidance information on the out-the-window scene allowed the pilots' attention to remain outside. They maintained faster taxi speeds while still being confident that they could detect and respond to unplanned outside events. In addition, pilots indicated a preference for the HUD.

For panel displays, there has been mixed results concerning the 3-D vs. 2-D issue for taxiing. Results indicate that reacting to unplanned ground traffic is more difficult with the 2-D display (Figure 2). Presumably, the difficulty arises because of the greater processing demands imposed by the 2-D display. 3-D displays have supported better (or equal) tracking performance with no shortcomings related to unplanned event detection.

Guidelines

- Utilize a HUD for taxiway navigation.
- The taxiway navigation display should be a 3-D display.
- Only information critical to the task should be presented on the display.
  Constraints and Comments
- There is a limited amount of research on the benefits of taxing with HUDs.
- The HUDs in these studies were relatively uncluttered. If the HUDs presented more information, then the performance advantages of the HUD and the 3-D display might diminish.

Key References

Lasswell, J. & Wickens, C. (1995). *The Effects of Display Location and Dimensionality on Taxi-way Navigation.* ARL-95-5/NASA-95-2. University of Illinois at Urbana-Champaign Technical Report. Aviation Research Laboratory.

Weintraub, D., & Ensing, M. (1992). *Human Factors Issues in Hhead-Up Display Design: The Book of HUD.* State-of-the-art-report, Crew System Ergonomics Information Analysis Center, Wright-Patterson AFB, Dayton, OH.

Wickens, C., Liang, C., Prevett, T., & Olmos, O. (1994) *Egocentric and exocentric displays for terminal area navigation.* (Tech. Rep. No. ARL-94-1/ NASA-94-1). Savoy: University of Illinois, Aviation Research Lab.

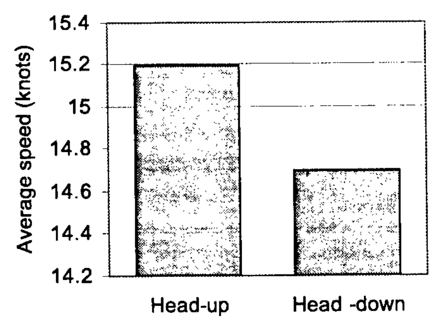

Figure 1. Average taxi speeds for display locations.

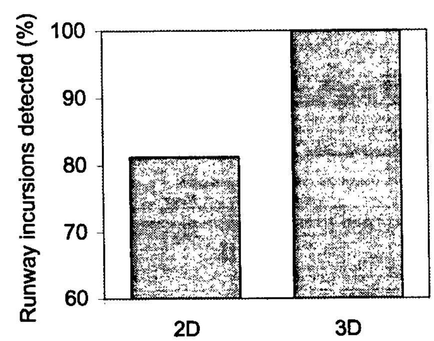

Figure 2. Runway incursions versus display type.

4.4 MFD Menu Organization

Introduction to Multifunction Display Menus

Background

"The development of increasingly capable computers and software tools, and advances in the design of displays has provided the technology for the evolution of the multifunction display (MFD)" (Francis, 1998). These advances permitted replacing the multitude of separate status, warning, and control devices with an integrated MFD. Since the inception of the MFD, crewmembers have pushed buttons to navigate through a hierarchy of display pages containing instructions, information, or lists of user-activated functions (Francis, 1998).

"MFDs have generally been credited with reducing cockpit instrument 'clutter' as well as reducing the time crewmembers spent searching for, and mentally integrating aircraft information" (Francis, 1998). The reduction in pilot workload due to the introduction of the MFDs was a primary factor in eliminating the need for flight engineers. However, with time, any reduction in workload was gradually offset by the tendency for MFDs to embody an increasing number of features and functions. This situation is similar to today's home computer. Today's computer is much more powerful than earlier versions, but since the number of functions has also expanded proportionally, it has become no easier to use. As a matter of fact, in the aviation world, there have been claims and instances were the workload with the current state-of-the-art MFD has actually been greater than with the less sophisticated systems (Francis, 1998).

In effect, MFDs "trade the workload associated with a visual search of the cockpit instruments for a cognitive workload associated with a search through mental images of a multidimensional database of pages" (Francis, 1998). The following sections describe many of the issues and research findings that can be used to aid in the design of these MFDs.

Key References

Francis, G. (1998). *Designing Optimal Hierarchies for Information Retrieval with Multifunction Displays.* U.S. Army Aeromedical Research Laboratory. Fort Rucker, Alabama. USAARL Report No. 98-33.

MFD Menu Organization

Background

The majority of MFDs incorporate hierarchical structures that define organization of content and navigational paths between display pages or modes. Navigation through the hierarchy is accomplished by the use of navigational objects such as menus, lists, and soft or hard keys. The user begins at the top page and then, through the activation of the keys or buttons, completes a sequence of selections that ultimately leads to the target selection/page (Francis & Reardon, 1997, Papp & Cooke, 1997).

"Despite the popularity of menu selection as a form of user-computer dialogue, until recently, very little has been known about the potential effects of menu structure on operator performance." (Snowberry, Parkinson, & Sisson, 1983). "In most interactive systems employing menu selection the number of items is far too great to list in a single display. Menu hierarchies can be arranged with many items on a menu and a minimum number of sequential menus (breadth) or with few lines on each menu and several levels (depth)." (Snowberry, Parkinson, & Sisson, 1983).

For many applications, the decisions to use breadth or depth in menu construction has been based on guesses about user characteristics rather than on data obtained from empirical studies. Many efforts have been completed in this area, and the research results have yielded general guidelines about the appropriateness of different organizations. (Seidler & Wickens, 1992).

Key References

Francis, G. & Reardon, M. (1997). Aircraft Multifunction Display and Control Systems: A New Quantitative Human Factors Design Method for Organizing Functions and Display Contents. *USAARL Report No. 97-18.* U.S. Army Aeromedical Research Laboratory. Fort Rucker, Alabama.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., and Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Seidler, K.S. & Wickens, C.D. (1992). Distance and Organization in Multifunction Displays. *Human Factors*, 34(5), pp. 555-569.

Snowberry, K., Parkinson, S. & Sisson, N. (1983). Computer Display Menus. *Ergonomics*, 26(7), pp. 699-712.

Depth versus Breadth in MFD Menus

Background

"The majority of menus are organized into a hierarchical tree, in which each menu panel in the hierarchy can be reached only" (Paap & Cooke, 1997) from a single node that lies directly above it. "Depth (d) is usually defined as the number of levels in the hierarchy. Breadth (b) is defined as the number of items or choices within each menu panel" (Paap & Cooke, 1997).

A structure with several layers of depth requires the user to either discover or recall how to get from where they are to where they want to go. These navigational requirements become "more and more treacherous as the depth of the hierarchy increases" (Paap & Cooke, 1997).

On the other hand, there are reasons for considering a system with greater depth. The obvious reason is crowding. The available space on the panel, and the required amount of space for the names and/or descriptors may require the need for more depth. Another attractive feature associated with depth is funneling. Funneling refers to a "reduction in the total number of options processed that can be achieved by designing a system where greater depth is traded for less breadth" (Paap & Cooke, 1997) – especially when the processing time per option is long. To clarify, consider a database with 64 options. If all the items appear as choices in a single panel, then an exhaustive search would lead to 64 options being processed. The other extreme would be to maximize depth and minimize breadth (d=6, b=2). An exhaustive search of both options on each of the six successive panels would entail only 12 options (Paap & Cooke, 1997).

As depth increases, the number of options to be processed decreases, but the number of panel transactions increases. "Each of the additional panels created by the increased depth requires one more response (e.g. key press, mouse selection) and one more response from the computer" (Paap & Cooke, 1997). For the example given above, the maximum depth organization would have six times the response-execution time compared with the single-panel case.

General Description

Lee and MacGregor (1985) proposed a quantitative method to estimate and then minimize the Total Search Time (TST) for the task. The formula calculates the average search time based on depth, breadth, processing time per option, human response time, and computer response time. For self-terminating searches, the formula to determine the optimal number of items per panel (b) is as follows (with b = breadth, k = human response time, c = computer response time, t = processing time per option)

Search time = $(bt + k + c)[(\log2\ N / \log2\ b)]$.

Depending on the various times, the optimal breadth is typically in the range of 4 to 13 items per panel. The longer the processing time per option, as compared to the execution time of the operator and the computer, the lower the optimal breadth will be.

Guidelines

- The number of options per panel (breadth) should be in the range of 4 to 13.
- The more demanding the task of processing individual options, the lower the breadth should be and the greater the depth should be.

Constraints

- These studies did not consider grouping as an aid.
- The menus in these studies were homogenous (each panel had the same number of choices and each choice had the same depth below it).
- Novice users were used in some of the studies.
- "Reasonable" human response times (.5 to 1 second) were used. These laboratory times may be different than "reasonable" rates in the cockpit.

Key References

Francis, G. & Reardon, M. (1997). Aircraft Multifunction Display and Control Systems: A New Quantitative Human Factors Design Method for Organizing Functions and Display Contents. *USAARL Report No. 97-18.* U.S. Army Aeromedical Research Laboratory. Fort Rucker, Alabama.

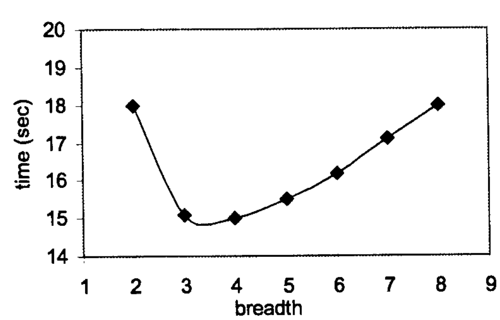

Figure 1. Theoretical times for 64 item menu navigation.

Lee, E. & MacGregor, J. (1985) Minimizing user search time in menu retrieval systems. *Human Factors*, 27 (2), pp. 157-162.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., and Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Varied Breadth in MFD Menus

Background

The majority of research on the topic of hierarchy depth and breadth concerns hierarchies that are both homogeneous and complete. That is, the hierarchies have the same number of options in each menu (homogeneous) and the same number of menus along each branch from top to bottom (complete).

Two related problems occur as a result of this limitation. First, since "in practice it is almost never possible to construct the recommended complete homogeneous hierarchy, it is not clear which hierarchy to choose as the optimal one. For example, if a hierarchy consists of 16 terminal options" (Fisher, Yungkurth, & Moss, 1990) and the optimal number of options per panel is calculated as 8, "it is not possible to construct a hierarchy with the recommended breadth because there is not integer value d such that $8^d = 16$." (Fisher, Yungkurth, & Moss, 1990). One is left to decide which of the many possible options is best.

Secondly, even if the recommended hierarchy is possible, there are still many structures that are not complete (i.e. same number of menus below each branch) but may be more efficient. For example, consider a hierarchy with 64 terminal items. "There are four complete, homogenous structures that can be created" (Fisher, Yungkurth, & Moss, 1990) e.g., breadth 64 depth 1, breadth 8 depth 2, breadth 4 depth 3, and breadth 2 depth 6. However, if one allowed the number of options per panel (breadth) to "vary between 2 and 64 (and not be kept constant as with the heterogeneous case), then it can be shown that there are more than a million different possible hierarchies. Any one of these hierarchies could be the optimal one" (Fisher, Yungkurth, & Moss, 1990).

This scenario relates to the issue of varying menu breadth across the level of depth. For instance, a 256 item menu could be organized as a decreasing menu (8 x 8 x 2 x 2), an increasing menu (2 x 2 x 8 x 8), a convex menu (2 x 8 x 8 x 2), or a concave menu (8 x 2 x 2 x 8) (Paap & Cooke, 1997). Or as was mentioned earlier, if the menu does not have to be "complete", it can be any one of thousands of other organizations.

General Description

Determining which one of the myriad of possible menu organizations is best is far from an exact science at this time. Much of it depends on questions relating to how intuitive, appropriate, and distinctive the categorizations are. Grouping is an extremely powerful tool and has been shown to aid the user – but only if the groupings are appropriate and not contrived. That is a judgement that the designer of the specific menu will have to make. In general, grouping simply for the sake of grouping does not improve the efficiency (Paap & Cooke, 1997).

As far as the general types of menus (e.g., increasing, decreasing, convex, and concave) is concerned, the pattern of depth that best funnels the user to the correct terminal panel should determine the optimal menu structure. For example, if the user's goal is vague, then two options in the top panel might be better than eight because the user is more likely to be clear on which of the two they should choose. On the other hand, if the target is explicit, then greater breadth might be advantageous because 8 choices on the top panel will likely be less ambiguous than two very general options.

In other words, if the user has "a clear idea of what they are looking for then its best to see 'all the cards laid out on the table in front of them' as soon as possible. This is true because potential errors are not caused by their failure to know what they are looking for, but rather by their failure to understand the organization of the menu." (Paap & Cooke, 1997). Conversely, if they are not sure what will satisfy or optimize their needs, "then 'playing a mini-version of twenty questions' at the top levels (Paap & Cooke, 1997) may funnel them directly to a target that would otherwise be difficult to find.

Indeed research has shown that for fuzzy targets, best performance occurs with the concave, and to a lesser degree, the increasing menu. These two panels are "bottom-loaded." That is, they have more breadth on the bottom panels and accordingly, the least amount of uncertainty across the upper levels (Paap & Cooke, 1997). Although the research is not overwhelming, breadth seems to be most advantageous at the top and bottom of the menu (concave).

Guidelines

- Careful consideration must be given to finding appropriate groupings for menu items. Grouping is a powerful aid for enabling superior performance.
- If the target is relatively "fuzzy" to the user, an organization with relatively little breadth at the top is recommended (i.e. "twenty questions" rule).
- If the target is much clearer to the user, then greater depth is recommended throughout (i.e. "lay out the cards" rule).

Constraints and Comments

- The optimum menu organization is dependent on how well the items lend themselves to being grouped.
- "Reasonable" human response times (.5 to 1 second) were used. These laboratory times may be different than "reasonable" rates in the cockpit

Key References

Fisher, D., Yungkurth, E., & Moss, S. (1990) Optimal menu hierarchy design: syntax and semantics. *Human Factors*, 32(6), pp. 665-683.

Norman, K. (1991) *The Psychology of menu selection: Designing cognitive control at the human/computer interface.* Norwood, New Jersey: Ablex.

Norman, K. & Chin, J. (1989) The menu metaphor. *Behavior and Information Technology*, 8, pp. 125-134.

Papp, K., and Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Item Selection in MFD Menus

Background

"The growing popularity of direct manipulation interfaces has resulted in a trend away from menu selection via discrete identifiers (i.e. typing in a letter or digit that represents an item), and toward menu selection via pointing" (Paap & Cooke, 1997). The menu items are usually selected by moving a pointer to the desired option and then selecting it. Cursor keys, joysticks, trackballs, touch screens, pens and mice are all examples of the devices used to manipulate the on-screen pointer. Knowledge of the merits of these various selection devices as they relate to MFD menu selection is desired.

General Description

The mouse has been found to be more efficient than a joystick or cursor keys in a task that had the subjects move the pointer over different distances to different sized targets (Paap & Cooke, 1997).

Other studies using a wider range of tasks found that the touch panel was superior to keyboard identifiers and the mouse. No interactions were found between the type of selector and the application or task type, suggesting that there is a consistent advantage with the touch screen (Paap & Cooke, 1997, Karat, McDonald, & Anderson, 1984).

Guidelines

- The use of a touch screen or a selection of buttons on the perimeter of the screen should be used in the design of the MFD.

Constraints

- There was not any physical difficulty in reaching and pressing the touch screen in any of these studies, as there may be in a dynamic cockpit.
- None of these studies were in an aviation context.
- Touch screens and not "screen-perimeter" buttons were studied.
- Test subjects were not pilots.

Key References

Card, S., English, W., & Burr, B. (1978) Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for selection on a CRT. *Ergonomics*, 21, pp. 601-613.

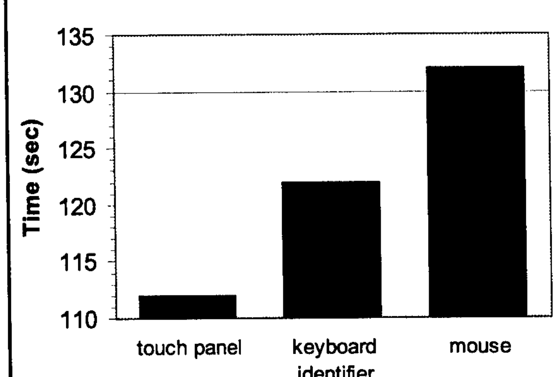

Figure 1. Average total time of realistic applications with various selectors.

Karat, J., McDonald, J., & Anderson, M. (1984) A comparison of selection techniques: Touch panel, mouse, and keyboard. *Proceedings of INTERACT '84.* pp. 149-153.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., and Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Item Organization in MFD Menus

Background

Many options have been proposed for the organization of MFD information. Alphabetical and categorical are two of the more prevalent choices. Additional ways to organize the MFD choices include frequency of use, ordinal dimension or magnitude, and temporal order (Paap & Cooke, 1997).

There is no single "best" way to organize MFD information. It is highly dependent on a variety of factors such as the type of data, the size of the lists, the familiarity of the user with the data, the affordance that the options allow towards being divided into distinctive categories, and on any constraints that may be imposed regarding the depth and breadth of the hierarchy.

General Description

General guidelines for the likely organization of the menu have been created based on a meta-analysis of the research conducted in this area.

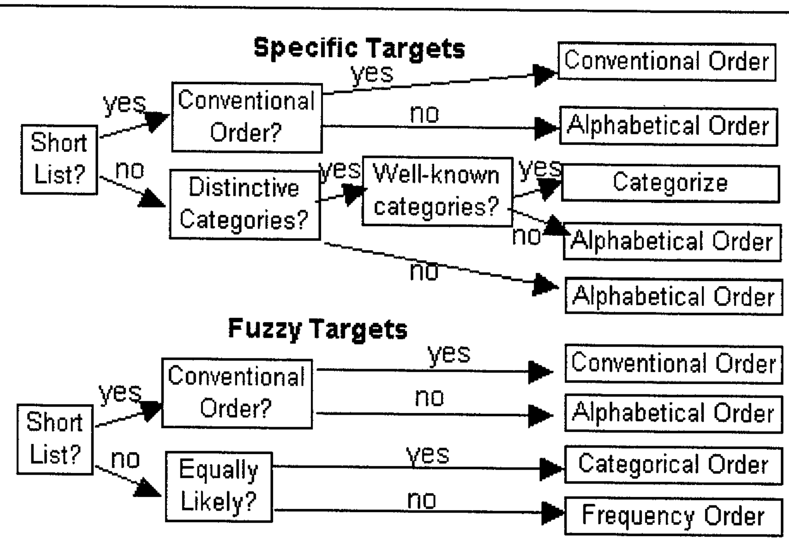

Figure 1. Guidelines for choosing an organization.

Figure 1 shows the guidelines. The top section presupposes that most users will have a specific target in mind that is highly likely to match one of the menu options. The next question to ask is whether the list of options is long or short. Those sets of options that have conventional orders are likely to be short and are likely to induce strong expectations for the options to be displayed in their familiar order. If the list is long, alphabetizing the selections may be beneficial. If the options can be arranged in categories that are both distinct (have little conceptual overlap) and well known to the end users, then grouping by category may be worthwhile.

The lower section of Figure 1 applies when users have only fuzzy targets in mind. For long lists, grouping by category will usually be the best strategy. One important exception to this case would be when a small subset of the options is selected much more frequently than the others. In this case, listing the options in decreasing order of frequency may be the better arrangement, particularly if the categories would not be distinctive or if the users may not be familiar with the instances of each category (Paap & Cooke, 1997).

Guidelines

- Use Figure 1 as an aid in menu organization decisions.

Constraints

- These guidelines are generalizations from specific research settings, and may not necessarily relate to the specific menu in question.
- There are many different ways to "categorize" menu choices after the decision has been made to use a "categorized" menu order.

Key References

Hollands, J.G. & Merikle, P.M. (1987). Menu organization and user expertise in information search tasks. *Human Factors,* 29(5), pp. 577-586.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Speech-Based Control of MFD Menus

Background

Speech recognition is one of the more mature of the so-called "non-conventional" or future technologies. Improvements in speech recognition algorithms have led to the realization of reliable, accurate continuous speech recognition. As advances in the field continue, speech command will become a common method of control i d:nput. An experimental F-16 jet aircraft has already been equipped with a limited vocabulary that controls the switching of various status information (McMillan, Eggleston, & Anderson, 1997). It is only a matter of time before commercial aircraft will have voice controlled features in the cockpit and the designers will have to deal with the human factors associated with such technology.

Some of the proposed advantages of voice control are:

1) "Voice commands allow for more possible responses to be given in a shorter period of time, without imposing added time-consuming manual components" (Wickens & Carswell, 1997).
2) "Voice options represent more compatible ways of transmitting symbolic or verbal information, than can be achieved by manual options" (Wickens, Vidulich, & Sandry-Garza, 1984).
3) "Voice options are valuable in environments when the eyes, and in particular the hands are otherwise engaged" (Wickens, Vidulich, & Sandry-Garza, 1984).
4) The "greatest payoff in task performance speed and accuracy is for complex information entry tasks that must be performed in conjunction with other manual or visual tasks" (Simpson, McCauley, Roland, Ruth, & Williges, 1987).

General Description

Much research and thought has gone into the design of various menu organizations (i.e., categorical, conventional, frequency). These design considerations improve performance especially for the novice user who is reasonably experienced with the organization, or when the options are infrequently used. In cases, though, when the user is extremely familiar with the set of options or when the menu items are repeatedly selected, identifier entry may be more efficient than manual selection. A good example of software taking this into consideration is Microsoft Word's allowance for both pointing and using identifier shortcuts for many of the menu items. These frequent menu selections are an excellent opportunity for the use of voice technology. Instead of requiring pilots to manually complete two or three menu selections to get to the desired display, a voice command shortcut that takes them directly to this oft-used display will lessen their workload. Even though the technology is implemented as an additional means to an end, it is very important that it be extremely accurate. If recognition accuracy is not in the high 90% range, pilots do not want it.

Guidelines

- Use voice command technology for the immediate selection of a particular item that may not be currently on the displayed level.
- Ensure that the voice recognition rate is at least 98% accurate.
- Immediate feedback should be provided to minimize any confusion to the user.
- The voice controls are supplemental to the traditional manual methods.
- A correction or "undo" capability must be provided to reduce the consequences of recognition errors.

Constraints

The most accurate speech recognition systems are user-specific (speaker dependent). There are design issues related to the relationship among speaker dependent versus independent systems, training and enrollment time, and performance (recognition accuracy).

Key References

McMillan, G., Eggleston, R., & Anderson, T. 1997) Nonconventional Controls. In G. Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* New York: Wiley and Sons. 729-771.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. 533-572.

Simpson, C., McCauley, M. Roland, E., Ruth, J. & Williges, B. (1987). Speech Controls and Displays,. In G. Salvendy (ed.) *Handbook of Human Factors.* New York. John Wiley.

Wickens, C., & Carswell, M. (1997) Information Processing in G. Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* Wiley and Sons. 89-129.

Shortening Navigational Distance in an MFD Menu

Background

"Navigational distance may be thought of as the number of steps required to arrive at the destination screen from any other screen. In the MFD, a step is simply a decision followed by a key press" (Seidler & Wickens, 1992). There are times when the pilot needs to scan between particular displays to make comparisons or carry out some sort of integration of information. The time and the distance to navigate up, across, and down the hierarchy are important considerations.

The introduction of identifiers to shorten the navigational distance in an MFD is one way to reduce navigation time. For instance, if direct access keywords are available, the navigational distance between any two screens could theoretically be one step away. Navigational distance also can be reduced by providing an option to jump instantly back to the top level or up one level (Seidler & Wickens, 1992).

General Description

The greater the navigational distance in an MFD, the greater the traversal time and the larger the decrement in memory accuracy (Figure 1). Both Previous and Main buttons were found to aid the users, with the Main button aiding the users more than the Previous button.

The utility of an MFD navigational tool, such as a direct access code to any screen, is greatest when used by pilots who are very familiar with the accessed screen. Voice control is one design option for a navigation tool.

In many communication environments, the most frequently used word, screen, or web page occurs much more often than the second most, the second much more often than the third, and so forth. This is referred to as Zipf's law (Zipf, 1949). That is, the frequency with which selections are used is a negative power function of their rank (figure 2). Individual pilots are likely to have a few screens that they call up much more frequently than others. The access code for these select, few screens will be most valuable to the pilot. Therefore, there may not be a requirement for the pilots to complete the cognitively demanding task of learning display access names for a large number of screens.

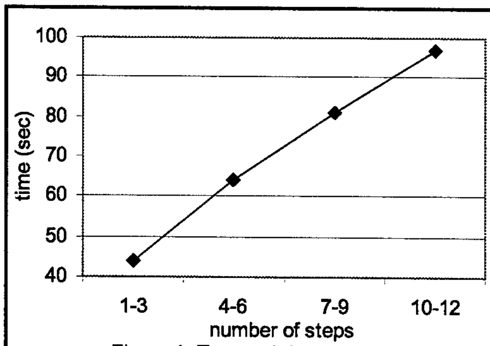

Figure 1. Traversal time as a function of number of steps.

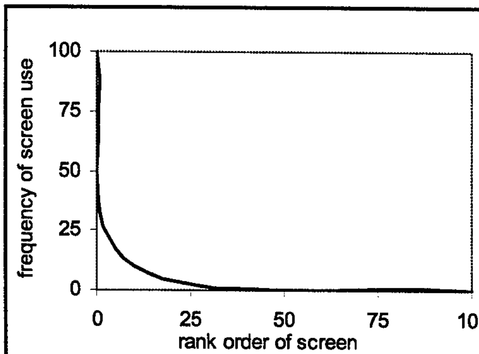

Figure 2. Theoretical relationship between screen selection usage and rank (Zipf's law).

Guidelines

- Include both a Previous and a Main button to help the pilot navigate.
- Provide direct access to all displays by entering an appropriate key word (or voice command).

Constraints

- The number of buttons and the design of the MFD varied considerably in the studies.

Key References

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. 533-72.

Seidler, K.S. & Wickens, C.D. (1992). Distance and Organization in Multifunction Displays. *Human Factors*, 34(5), 555-69.

Wickens, C., & Carswell, M. (1997) Information Processing in G. Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* Wiley and Sons. 729-71.

Category Organization in an MFD Menu

Background

Lee and MacGregor (1985) conducted research in the area of menu depth and breadth. Their results led to a formula that would describe the optimal depth and breadth for a particular menu based on various processing times.

If reasonable processing and response times are put into the formula, the results lead to the recommendation to have between 4 and 13 items per panel (depending on the specific processing times). Their algorithm, however, ignores the option of organizing the data into categories within the panel. In addition, the effect of user's experience on the organization of data was not included in the formula.

Roske-Hofstrand and Paap (1986) extended the original work to include the effect of experience and the value of data categorization.

General Description

Experience with the same set of menu panels will shrink the scope of the search because the subjects now know the general location of their next item choice. In fact, "eye movement analysis showed that after 800 selections from the same menu the target was always found on the first fixation. With experience, menu users move from a state of great uncertainty concerning the location of the target to one of near complete certainty" (Paap & Cooke, 1997).

The optimal breadth is very sensitive to experience effects. As the users experience grows, the optimal breadth increases. For the condition in which no grouping is applied and in which the optimal breadth is found to be eight, this value grows to 38 as expertise is gained (Paap & Cooke, 1997).

A similar reduction in the time to complete the search takes place when the options within an individual panel are organized. Grouping is an extremely powerful influence in the depth-breadth trade-off.

"For self-terminating search tasks, optimal menu sizes will usually be between 4 and 8 and may sometimes be as high as 13" (Paap & Cooke, 1997). In contrast, when meaningful groups of options can be presented for each menu, the "optimal breadth tends to be in the range of 16 to 36 and sometimes as high as 78" (Paap & Cooke, 1997; Figure 1).

One way to think about the benefits of categorization is that it accomplishes the same goal as funneling. Funneling refers to the reduction in the number of options that can be chosen to guide the user to the appropriate path. Categorizing the menu options within the panel enables the user to realize the benefits of funneling, but without the response and execution time costs associated with greater depth.

Guidelines

- If meaningful groups of options can be presented for each menu, then the optimal breadth can increase from the 4 to 8 range, to the 16 to 36 range.
- The more experienced the user is with the organization, the greater the breadth should be.

Constraints

- The menus in these studies were homogenous (each panel had the same number of choices and each choice had the same depth below it).
- "Reasonable" human response times (0.5 to 1 second) were used. These laboratory times may be different than "reasonable" rates in the cockpit

Key References

Card, S., English, W., & Burr, B. (1978) Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics*, 21, pp. 601-613.

Francis, G. & Reardon, M. (1997). Aircraft Multifunction Display and Control Systems: A New Quantitative Human Factors Design Method for Organizing Functions and Display Contents. *USAARL Report No. 97-18*. U.S. Army Aeromedical Research Laboratory. Fort Rucker, Alabama.

McDonald, J., Stone, J., & Liebelt, L. (1983) Searching for items in menus: The effects of organization and type of target. *Proceedings of the Human Factors Society 27th Annual Meeting* (pp. 834-837). Santa Monica, CA: HFS.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction*. Elsevier Science Pub. pp. 533-572.

Roske-Hofstrand, R. & Paap, K. (1986). Cognitive networks as a guide to menu organization: An application in the automated cockpit. *Ergonomics*, 29(11), pp. 1301-1311.

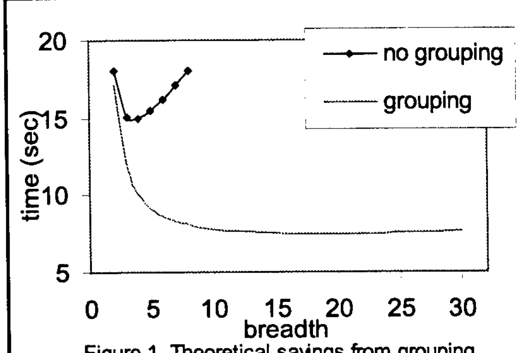

Figure 1. Theoretical savings from grouping items.

Organizational Aids for the Design of an MFD Menu

Background

It is important to properly categorize and organize the items in an MFD menu. In some cases, the categories are well known and distinct, and the intuitions of the designer match those of the users. However, in most cases the optimal organizational scheme is not obvious. Software engineers must overcome the temptation to generate their own organizations or to consult with only a single expert.

If items are categorized according to the users' perceived organization, users will locate items more quickly and with fewer errors. Menu organization also affects the formation of the users' conceptual models of the system (McDonald, Stone, & Liebelt, 1983). In cases where the user is a novice, the schema created by the more experienced and more typical users can help the novice develop a well-formed domain schema, thereby easing the transition from novice to system expert (Paap & Cooke, 1997). These advantages can not be realized when system designers generate their own organizational scheme.

The practice of obtaining the users' input to guide the design is one of the main principles of user-centered design.

General Description

There are many user-centered design success stories. Arguably, all design success is a result of applying, to varying degrees, the techniques, processes, methods, procedures, and philosophy that places the user at the center of the design process.

Research on menu organization has indicated that "organizations generated from user data are superior to those based on designers' intuitions" (Paap & Cooke, 1997). The menus based on user organization resulted in fewer errors, shorter selection times, and better recall, than the sortings of software designers. Research on MFDs also has shown similar advantages when the organization is ordered by groups of pilots, not designers or single experts in the field. It is insufficient to give the users category labels and have them assign the individual items to these pre-formed categories. In general, menus generated by multiple users outperform those generated by "experts" or the designers.

Guidelines

- Menu organizations should be based on data collected from multiple users (pilots) who are representative of the target population.
- The users should have complete freedom in determining the organization and should not be constrained by the designer's preconceptions of categories.
- The techniques, methods, and philosophy of the user-centered design process should be adhered to. (See ref. 4 for a description of the process).

Constraints and Comments

- Care needs to be given to insure that the users' inputs are being provided and analyzed without any influence from the preconceptions of the designers.

Key References

Roske-Hofstrand, R. & Paap, K. (1986). Cognitive networks as a guide to menu organization: An application in the automated cockpit. *Ergonomics*, 29(11), pp. 1301-1311.

Rubin, J. (1994). The problem of unusable products and systems. *Handbook of Usability Testing*. Wiley and Sons. pp. 3-23.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction*. Elsevier Science Pub. pp. 533-572.

Seidler, K.S. & Wickens, C.D. (1992). Distance and Organization in Multifunction Displays. *Human Factors*, 34(5), pp. 555-569.

Network Structures in an MFD Menu

Background

The majority of the menu organization research has concerned single-linked hierarchical issues. In particular, depth versus breadth issues. Comparatively little research has been conducted concerning alternate types of hierarchies. For instance, a network organization instead of a structured, single-linked hierarchy.

"A network consists of a set of nodes and a set of links that connect the related nodes" (Paap & Cooke, 1997). The important difference between the network and the traditional hierarchy is that each "node may have any number of incoming and outgoing links and the only requirement is that each node in a connected network must have at least one entry and one exit. One potential advantage with this kind of arrangement is that it can provide redundant pathways to the same menu panel" (Paap & Cooke, 1997). For many applications, a given panel naturally belongs to more than one general category – a case that the single-linked hierarchy would not be able to satisfy.

The goal of the designer of the MFD should be to create an organizational menu structure that is consistent with the user's cognitive model. A software tool known as Pathfinder has been designed to empirically obtain this conceptual user organization.

Pathfinder (and other software tools) generate the family of link-weighted networks from any set of "distance" data. The distance data can be measures of functional similarity, physical similarity, co-occurrence, frequency of selection, or any other relationship (Roske-Hofstrand & Paap, 1986, Seidler & Wickens,1992).

General Description

A cognitively guided network (i.e. one developed using tools such as Pathfinder) that offers the maximal number of meaningful pathways from the top level to the bottom level is easier to learn and use than the traditional hierarchical model (Roske-Hofstrand & Paap, 1986, Figure 1.).

Guidelines

- Menu organizations should be based on the pilots' conceptual organization of the domain.
- The input from the pilots should be used as the data for a Pathfinder type of tool that can be used to determine possible network organizations.

Constraints and Comments

- Consideration needs to be given to the difference between increased efficiency during the menu learning phase and during the longer operational phase.

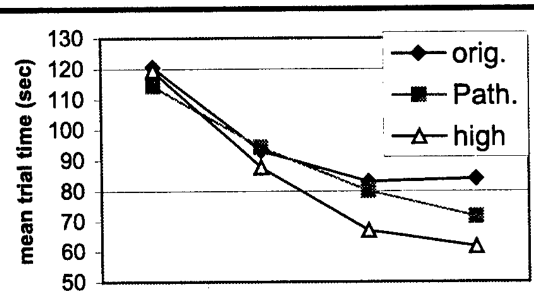

Figure 1. Mean trial time over tests for original menu, Pathfinder-designed, and a highly redundant Pathfinder menu (sec)

- Design decisions are still required concerning exactly which of the links should be included (i.e., how "strong" and "meaningful" is "strong and meaningful" enough?).

Key References

Roske-Hofstrand, R. & Paap, K. (1986). Cognitive networks as a guide to menu organization: An application in the automated cockpit. *Ergonomics*, 29(11), pp. 1301-1311.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., and Prabhu, P. (eds), *Handbook of Human-Computer Interaction.* Elsevier Science Pub. pp. 533-572.

Adding Descriptors to the MFD Menu

Background

The total set of MFD options will likely be layered across multiple menu panels, thus requiring the user to navigate through the hierarchy to find the display of choice.

The majority of errors in these menu-driven systems occur because the meaning of the options is not clear to the user. Users may make a particular selection only to later realize that they are heading down the wrong path. They will then have to back up and reselect a more appropriate path. This is both time-consuming and frustrating to the pilots.

One method of increasing the clarity of the menu choices is to append an expanded descriptor to each key word or phrase. Descriptors can include examples of items in the next layer down in the menu hierarchy. Presumably, the use of descriptors or key words will significantly reduce the number of dead ends that the pilot encounters.

General Description

The results of studies have clearly demonstrated that descriptors can be very effective when users have had limited experience with a menu panel. They are particularly helpful when the menu consists of options among general and abstract categories. Under these conditions, menus with descriptors result in fewer errors and are much preferred by users.

The more abstract the categories, the more descriptors are needed to provide the user with an understanding of the range of items contained in that category. Also, knowledge of the upcoming options was useful in making choices at the higher levels, but was not as helpful at the lower levels.

Including a miscellaneous category into the menu choices creates a great deal of confusion and entices the navigators to the wrong path. This result is a good illustration of the power that context can play on the selection process. That is, the goodness of a name is very much determined by the other names appearing on the menu panel. Again, the importance of carefully choosing and organizing the hierarchy is seen.

Guidelines

- The options presented in an MFD menu display should include descriptors with them.
- The more abstract, difficult, or infrequently used the options, the more descriptors are required.
- The descriptors that are given should be examples of the next level down in the hierarchy, not middle level choices.
- All things being equal (i.e. frequency of use and familiarity with), the further down the hierarchy, the less helpful the descriptors. Note that typically those choices further down are infrequently selected and are therefore likely to require more descriptors, not less.
- General "catch-all" choices such as miscellaneous should not be used.

Constraints and Comments

- There is a trade-off between the extra time required to scan the choices with descriptors, and the time cost associated with navigation errors.
- Familiarity with the menu may lessen the value of descriptors relating to frequently used choices.

Key References

Dumais, S., & Landauer, T. (1983) using examples to describe categories. *Proceedings of CHI '83*. pp. 112-115.

Lee, E., Whalen, T., McEwen, S., & Latremouille, S. (1984) Optimizing the design of menu pages for information retrieval. *Ergonomics*, 27, pp. 1051-1069.

Papp, K., and Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction*. Elsevier Science Pub. pp. 533-572.

Snowberry, K., Parkinson, S., & Sisson, N. (1985) Effects of help fields on navigating through hierarchical menu structures. *International Journal of Man-Machine Studies*, 22, pp. 479-491.

Debunking the Icon Myth

Background

Many software applications have incorporated icons as aids in selection. These icons may be joined with the text descriptions, may be used in lieu of those descriptions, or may be an additional way to select the particular option. There are three possible advantages that icons may have over textual options. First, if icons replace words as target alternatives, then there are situations in which the display can be searched in parallel and there is a lowered cost associated with having a large number of options on a single panel (Wolfe, 1994, cited in Paap & Cooke, 1997). Second, categorization of pictures can sometimes be faster than words (Pellegrino, Rosinkski, Chiesi, & Siegel, 1977, cited in Paap & Cooke, 1997). Third, "icons, like descriptions, can provide additional information that increases the accuracy of selections" (Paap & Cooke, 1997).

General Description

A tradeoff in the design of distinctive icons has been found. For instance, when the distinctiveness of an icon is enhanced by using simpler figures, it is likely that the simplification will make the icon more abstract and more error prone. On the other hand, more representational icons will be scanned sequentially and slower - just like the words that they were designed to replace (Paap & Cooke, 1997).

When icons are added to verbal labels, search times are improved. However, an equivalent improvement can also be realized by adding a verbal example. The results can be stated simply— supplementing category labels with icons is equivalent to adding a one-word example.

Icons have very little value, as compared with verbal descriptors, when they are combined with verbal labels. For icons to be useful as stand-alone labels, they must have enough detail about both the "object and action to make them highly representational and easily understood" (Paap & Cooke, 1997). Often, these requirements will eliminate the icon's visual distinctiveness (Paap & Cooke, 1997).

Guidelines

- Use verbal descriptors, not icons, to provide more information on a menu category.
- In general, use icons sparingly. Their stand-alone value is difficult to realize, and their value combined with labels is no better than that of a verbal descriptor.

Constraints and Comments

- The presumed value of icons as space saving "short-cut" selections to frequently used tasks was not analyzed in these studies.

Key References

MacGregor, J. (1992) A comparison of the effects of icons and descriptors in videotext menu retrieval. *International Journal of Man-Machine Studies*, 37, pp. 767-777.

Papp, K., & Cooke, N. (1997) Design of Menus in Helander, M., Landauer, T., & Prabhu, P. (eds), *Handbook of Human-Computer Interaction*. Elsevier Science Pub. pp. 533-572.

Wolfe, J. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic bulletin and Review*, 1(2), pp. 202-238

4.5 Automation

Cockpit Automation

Background

> "The modern airplane is the product of a program of research, development, and refinement in detail that no other structure or mechanism has ever matched. The results have been so remarkable that there is always danger of forgetting that these extraordinary craft still have to be operated by men, and that the most important test they have to meet is still being operable without imposing unreasonable demands or unnecessary strains on the flight personnel."
>
> —Edward Warner, 1946

As in many other cases involving modern technology, the question regarding automation is no longer "Can we do it?", but "Should we do it?"

The degree to which the modern aircraft has been automated is astounding. The newer aircraft "can operate almost unassisted from shortly after takeoff until they come to a rest after landing. Indeed, if all goes well, the human operator's cognitive and psychomotor skills are hardly called upon" (Billings, 1997).

Automation technology was originally developed with the hope of "increasing the precision and economy of operations while, at the same time, reducing operator workload and training requirements. It was considered possible to create a system that required very little or no operator intervention, and therefore reduced or eliminated the chance of human error within the system" (Sarter, Woods, & Billings, 1997). This original view of automation is based on the assumption that automating tasks that the human would ordinarily do would have no larger impact on the system in which that task occurred. In other words, the tasks that make up the larger system are essentially independent. "However, investigations into the impact of the introduction of automated technology into the cockpit have shown that this assumption is not correct. Tasks and activities are highly interdependent in actual, complex systems" (Sarter, Woods, & Billings, 1997).

As a result of this interdependency, "only some of the benefits of automation have been realized" (Sarter, Woods, & Billings, 1997). "There has been a sharp decline in certain types of accidents that appear almost certainly to be due to the introduction of automation aids" (Billings, 1997). On the other hand, "several accidents and a large number of incidents have been associated with and caused by the interaction between automation and the human operators" (Billings, 1997). The general issues raised concerning automation in the cockpit also apply to the specific case of automating the display of information on a multifunction display.

Control automation "assists or supplants a human pilot in guiding an airplane through the maneuvers necessary for mission accomplishment" and has followed "a generally evolutionary path" (Billings, 1997). Unlike the gradual advancements realized in control automation, information automation "has been marked by major changes due to the introduction of electronic display units (EDUs)" (Billings, 1997). The EDU capability "has made it possible to provide any sort of information in new and different formats" (Billings, 1997) and to modify and automate the presentation of that information in any way desired.

Of particular relevance to MFDs, are the automation of aircraft subsystem displays. Although there is "still a philosophical controversy about the necessity of providing synoptic [summarized diagrammatic] subsystem information," (Billings, 1997) many pilots find it desirable to have such displays in the cockpit.

Automation issues become important when an anomaly occurs in a subsystem. Should a new subsystem display be brought up automatically or should the pilot have to do it? As the Douglas Chief of MD-11 operations put it, "One of our fundamental strategies has been, if you know what you want the pilot to do, don't tell him, do it" (Hopkins, 1990). However, the strategy of automatically reconfiguring the displays can lead to a failure to present the "basic or root causes of the faults in the MD-11...and presents the potential for pilot confusion or surprises" (Billings, 1997).

Control automation was brought into the cockpit with good intentions, but has resulted in mixed results. Similarly, information automation was introduced to "alleviate pilot workload when dealing with anomalies" (Billings, 1997), but can instead increase the cognitive demand on the pilots.

Numerous design issues arise from the original question of "Should we do it (implement the automation aid)?" The difficulty with creating automation rules that can be generalized into specific guidelines is similar to the difficulty with creating specific display guidelines that are applicable to all displays (see section 6). Each automation design choice has a unique set of pertinent issues and "questions." It is difficult (if not impossible) to create a guideline that can be applied broadly across different design conditions.

Specific guidelines exist and can only be created with an in-depth understanding of the design objectives, the constraints, the conditions, the operating environment and the interrelations of these factors. As Billings (1997) put it, "I do not believe that specific "how-to" guidance is appropriate or particularly useful except in the context of a particular system, within which there may be several, perhaps equally effective, ways to implement a particular function."

Many of the problems with automated systems are traceable to a "technology-centered" design process. A collection of specific guidelines will not alleviate the problems with automation. A change in the design process is the best way to counteract and prevent the difficulties. This new approach to the design process is a subset of the "human-centered design" discussed earlier, and is called "human-centered automation" (HCA) (Billings, 1997).

There are many general guidelines or principles concerning automation that can aid the designer during the human-centered automation design approach. The following sections describe some of these principles, along with the nature of automation difficulties.

Key References

Billings, C. (1997). *Aviation Automation: The Search for a Human-Centered Approach.* Erlbaum Ass., Pub. New Jersey.

Sarter, N., Woods, D., & Billings, C. (1997). Automation Surprises. In G.Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* Wiley and Sons. pp. 1926-1943.

Automation Problems: Feedback

Background

One problem with automation complexity is that the automation does not help the operators understanding of what is being controlled. "In earlier times, less capable automation simply controlled the airplane's attitude and path; pilots could usually understand exactly what it was doing by observing the same instruments they used when they were controlling the aircraft manually" (Billings, 1997). Today's automation is far too complex to accomplish this. "The information about what it is doing is almost always available somewhere in some form, although not necessarily in terms that the pilot can easily decipher. Why it is behaving a particular way and what it is going to do next is often not available except maybe in the requirement documents that motivated [the design]" (Billings, 1997).

This problem is often referred to as the paradox of technology. Technology offers the potential to make things easier; to provide increased benefits. At the same time, added complexities arise to increase the user's workload and frustration. As the product becomes more complicated, it becomes more important to provide proper feedback to the user (Norman, 1990). Designers often purposely avoid presenting feedback of the automation process to keep the pilot from being overburdened with information that is not essential to the necessary functions (as understood by the designer).

There is certainly a trade-off in the design decision regarding feedback. Opacity (lack of feedback) at some level is required so as not to overwhelm the pilot. It is important to consider that the ability of pilots to assimilate information is context dependent. When more data is presented without adequate consideration of the context, it becomes less likely that pilots will attend to the most important data.

With modern computers and graphics capabilities, the designer now has the option to show what is really happening, to provide a good image that matches the person's mental model of the task – thereby simplifying both understanding and performance. Three questions with which Wiener (1989) paraphrased the frequent responses of pilots to automation surprises were, "What is it doing?," "Why is it doing that?," and "What is it going to do next?" Providing adequate and context specific feedback to the pilot can help answer these questions.

Key References

Billings, C. (1997). *Aviation Automation: The Search for a Human-Centered Approach.* Erlbaum Ass., Pub. New Jersey.

Norman, D. A. (1990). *The design of everyday things.* New York: Doubleday.

Automation Problems: Complexity

Background

Current aircraft automation systems are capable, flexible, and very complex. When there is a problem, the pilot is expected to solve it. When the pilot perceives that automation has introduced an error, the pilot may not have a mental model of the system that enables proper diagnosis and corrective action. In this case, the pilot may revert to a lower level of management or may attempt to turn off the automation, which may unintentionally disable certain protective features (Curry, 1985).

Mode errors are another problem arising from the flexibility of automation. Modern systems may have several modes for each of several control elements.

General Description

Norman (1990) explains that changing the rules often leads to errors. An example of changing the rules is a system that allows something be done one way in one mode and another way in another mode. Mode errors occur when a user executes an intention in a way appropriate for one mode when the system is in a different mode. Advanced systems are capable of changing modes (or modes within a mode) autonomously. This capability for "indirect" mode changes without direct instructions from the pilot creates the potential for additional mode errors. Breakdowns in mode awareness are thought to have contributed to a number of incidents and accidents (Sarter, Woods, & Billings, 1997).

The flexibility of more advanced systems tempts automation designers to develop more complex and mode-rich systems. Not only has the number of modes increased, but also the complexity of their interactions (Sarter, Woods, & Billings, 1997).

Guidelines

- Minimize the number of modes in the automation.
- Eliminate or limit the number of mode changes initiated by the software.
- Ensure that if a procedure is done one way in one mode, it is done the same way in all modes.

Key References

Billings, C. (1997). *Aviation Automation: The Search for a Human-Centered Approach.* Erlbaum Ass., Pub. New Jersey.

Curry, R. (1985). *The introduction of new cockpit technology: A human factors study* (NASA Tech. Mem. 866659). Moffett Field, CA: NASA-Ames research Center.

Norman, D. A. (1990). *The design of everyday things.* New York: Doubleday.

Sarter, N., Woods, D., & Billings, C. (1997). Automation Surprises. In G.Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* Wiley and Sons. pp. 1926-1943.

Automation Problems: Workload

Background

The introduction of automation into the cockpit was expected to reduce crew workload. "It turned out, however, that automation does not have a uniform effect on workload" (Sarter, Woods, & Billings, 1997). Many automated systems tend to support pilots during low-workload phases of flight but are of no use, or even act as a hindrance, when they are needed most – during time-critical dynamic situations (Sarter, Woods, & Billings, 1997).

One reason for this dilemma is that automation does not have access to all the flight-relevant data. Therefore the crew must spend their time providing information to the automated system, deciding how automation should go about achieving the goal, and monitoring the automation closely to ensure that commands have been received and are being carried out as desired (Sarter, Woods, & Billings, 1997).

"Workload is not only unevenly distributed over time, but it is sometimes unevenly distributed over the crew also" (Sarter, Woods, & Billings, 1997). For example, on many advanced flight decks the pilot-not-flying can be much busier than the pilot-flying because they are responsible for most of the interaction with the automation interface (Sarter, Woods, & Billings, 1997).

Key References

Curry, R. (1985). *The introduction of new cockpit technology: A human factors study* (NASA Tech. Mem. 866659). Moffett Field, CA: NASA-Ames research Center.

Norman, D. A. (1990). *The design of everyday things.* New York: Doubleday.

Sarter, N., and Woods, D. (1995) *Strong, silent, and out-of-the-loop: Properties of advanced, cockpit automation and their impact on human-machine coordination* (Tech. Rep. No. 95-TR-01). Cognitive Systems Engineering Lab., Ohio State Univ.

Sarter, N., Woods, D., & Billings, C. (1997). Automation Surprises. In G.Salvendy (ed.) *Handbook of Human Factors and Ergonomics.* Wiley and Sons. pp. 1926-1943.

Automation: Human-Centered Approach

Background

> "There are disquieting signs in recent accident investigation reports that in some respects our applications of aircraft automation technology may have gone too far too quickly, without a full understanding of their likely effects on human operators" (Billings, 1997).

The concept of human-centered automation is an attempt to reevaluate the human-machine interactions with the hopes of avoiding many of the automation problems that now confront pilots. "The thesis of this approach is that by beginning with the human and designing tools specifically to complement the human's capabilities, we can build more effective and robust systems that will avoid or ameliorate many of the automation problems" (Billings, 1997).

The following sections describe the principles of human-centered automation with some discussion on each. For a more thorough description, reference 1 is recommended.

Guidelines

- **The human operator must be in command.**
- **Assist the pilot by providing an appropriate amount of feedback on the system.**
- **Automation exists to *assist* pilots in carrying out responsibilities.** Automation cannot deal with uncertainty, does not have comprehensive knowledge of world states, and should not be in control. This means that the pilot's responsibilities include detecting shortcomings in the automation's behavior, correcting it when necessary, and continuing the operation.
- **The human operator must be involved in order to command effectively.** To be involved is "to be drawn in." The pilot must have an active role, whether the role is to control the aircraft directly, or to manage the machine resources through which control is being exercised.
- **Pilots should be required to complete meaningful tasks** that have perceptual, cognitive and psychomotor components so that pilots must perceive, detect, think about and respond actively to the stimulus. The goal of automation is not to alleviate the pilot of all the tasks. The pilot must be involved.
- **To remain involved, the human operator must be appropriately informed.** Without appropriate information concerning the operation, pilot involvement becomes less immediate and decisions become unpredictable.
- **The human operator must be informed about automated systems behavior.** It is necessary that pilots be aware both of the function (or malfunction) of the automated system and of the results of its processes, if they are to understand the behavior of the automated system.
- **Automated systems must be predictable.** To know what automation to use, the pilot must be able to predict how the airplane will be affected by the particular automation, not only at the time that it is selected, but throughout the duration of the flight. It is also important that the pilot understand the full range of allowable behaviors of the automation aid.
- **Automated systems should monitor system faults and errors and should convey diagnostic and corrective information.** Much effort has gone into making critical elements of the aviation system redundant. Because hardware, software, and humans all are capable of error, it is necessary that error detection, diagnosis, management, and correction be integral parts of automated systems (Wiener, 1993).
- **Each agent in an intelligent human-machine system must have knowledge of the intent of other agents.** Cross-monitoring of machines by humans, of humans by machines, and of humans by humans can only be effective if the agent doing the monitoring understands what the monitored agent is trying to do.

- **Functions should be automated only if there is a good reason for doing so.** If the time within which action is required following a signal or stimulus is less than will normally be required for detection, diagnosis, and decision to act, the task should be considered for automation.
- If a task is very complex, requires many rote steps, or if the task is very difficult to perform correctly, the task should be redesigned or considered for automation.
- If a complex task, improperly performed, will lead to a high probability of an adverse outcome, the task should be redesigned or, if this is not possible, considered for automation.
- If a task is boring, repetitive, or distracting, especially if it must be performed frequently, that task should be considered for automation.
- **Automation should be designed to be simple to learn and to operate.**
- **Automated systems must be comprehensible.** As automation becomes more complex, it is likely to become more tightly coupled, with more potential interactions among modes. Pilots must be helped to understand the implication of these interactions.
- **Automation must insure that operators are not removed from the command role.** Increasing integration and coupling of the ground and airborne elements of the Air Traffic Control system have the potential to bypass the pilots. One way to guard against this is to design future flight management systems so that the pilot is shown the consequences of any clearance before accepting it.
- **All automation elements and displays must enhance situation awareness.** The minimum elements for situation awareness are a knowledge of the airplane's position, velocity, attitude, error rate, status, threats, the status of the aircraft control automation and other aids, what must be done next, and when it must occur.
- **Automation must never be permitted to perform, or fail, silently.**
- **Management automation should make human-machine systems easier to manage.** A major problem with flight management systems is that they are cumbersome to operate.
- **Control automation must not be permitted to become "insubordinate."** Control automation should not be allowed to endanger an aircraft by causing an overspeed, a stall, or a contact with the ground.
- **Pilot authority to override normal operating limits should not be removed by the automation.** Pilots may find it necessary to deliberately exceed safe operating limits to complete the mission with the highest degree of safety.
- **Aircraft control automation should be designed to be of most help during times of highest worn:kload.**
- **Automation should be designed for maximum error resistance and maximum error tolerance.** The simplest possible architecture, clear, intuitive displays, and unambiguous responses to commands should be designed.
- **Emphasize information in accordance with its importance.** The most important information should be most obvious and most centrally located.

Key References

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Tenney, Y., Rogers, W. & Pew, R. (1995). *Pilot Opinions on high Level Flight Deck Automation Issues: Toward the Development of a Design Philosophy.* NASA Contractor Report 4669. Prepared for Langley Research Center. Contract NAS1-18788.

4.6 Individual Displays: *3D Versus 2D Displays*

Background

As summarized by Wickens, Todd, and Seidler (1989), there are both benefits and costs associated with using a 3D (perspective) aviation display. One benefit is that a 3D visual scene is a more natural, "ecological," or compatible representation of the 3D world than that provided by 2D displays. Another benefit is that a single integrated display of a 3D scene reduces the need for mental integration of multiple 2D displays.

"Conversely, a cost associated with using 3D displays is that any projection of a 3D world inevitably produces an inherent perceptual ambiguity" (Liu, 1997). Depth is represented less accurately because the 3D display has to indicate distance in a nonlinear fashion. For any given 2D point within the display, there are an infinite number of potential 3D positions. Although a 3D display enables the user to achieve a holistic perception of the scene, it is more difficult to make accurate judgements on relations or values along any axis, particularly when one attempts to judge the distance between two points along the line of sight (Liu, 1997). Also, 3D displays are more susceptible to clutter (Garner, 1970).

There is no shortage of studies examining the merits of 3D versus 2D displays in the aviation journals. There is however, a shortage of consistent and clear results illustrating the comparative benefits of the displays.

Haskell and Wickens (1993) have introduced a concept known as the Proximity Compatibility Principle (PCP) that has helped to explain the seemingly inconsistent results that the research has produced. The PCP predicts that "more integrated tasks will benefit from more integrated displays (the 3D display), whereas this benefit will be reduced, eliminated, or even reversed for tasks requiring focusing attention" [on information from a single source] (Haskell & Wickens, 1993). Hence, there is a "compatibility" between proximity of information sources and do:egree of mental integration of these sources required by the task. The PCP predicts, for instance, that a 3D display will be superior for flight control (and for other integration tasks), but will be inferior for tasks that require precise readings along certain axis (e.g., vertical separation of aircraft, check reading altitude) (Haskell & Wickens, 1993). With the PCP concept in mind, the following general descriptions are excepted from selected research on the merits of 3D versus 2D displays for traffic, navigation, and weather displays.

General Description

Traffic Display: The information derived from traffic displays involves both types of requirements, integrated and focused, and therefore may not clearly be benefited by either a 3D or a 2D display. That is, there is a need to integrate the "parts" of the scene (which would presumably be aided by a 3D display), while the need to judge specific distances in a particular direction (aided by a 2D display) is also required.

For a visual search and a tracking task performed using a traffic display, a 3D display enabled the pilots to perform better than with the 2D display. However, for a conflict detection task, subjects performed better with the 2D coplanar display than the 3D display. Not only were more conflicts avoided, but the response times were shorter (Figures 1,2). In addition, the pilots initiated more avoidance maneuvers in the wrong direction while using the 3D displays and subjective workload ratings also were lower for the 2D coplanar display.

Navigation Display: Currently, commercial aircraft displays exhibit primarily orthographic projections – "two dimensions without any information about the dimension not explicit in the display. When these displays do present information regarding that dimension, they present it alphanumerically" (Haskell &Wickens, 1993).

The demand on pilots to integrate data are already quite high, and the fact that the "dimension not explicit in the display" consists of alphanumerics can only increase the cognitive demands of integration. The inclusion of alphanumeric information requires the pilot to mentally transform and then integrate the data with the spatial information from the displays. The task of estimating the rate of change of these data points is also more difficult with the data in a 2D format. A 3D display would seem like a way to alleviate these problems because all three dimensions are presented spatially and a much more realistic

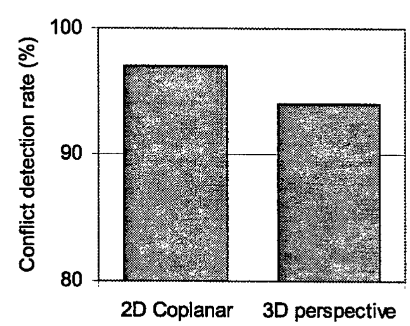

Figure 1. Conflict detection rate for different displays.

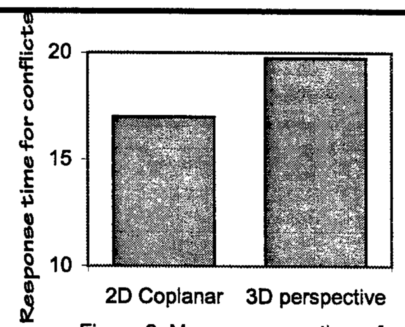

Figure 2. Mean response times for conflict trials (correct detections only).

picture of the environment is produced. Indeed, for a three-dimensional, spatial, dynamic task (e.g., lateral and altitude control), a 3D display is preferable (Figure 3). While for tasks that require attention to be focused on a single axis (airspeed control), a 2D display is superior. Again, these results are consistent with the PCP.

Weather Display: According to the Federal Aviation Administration (as cited in Wickens, Campbell, Liang, & Merwin, 1995) weather is cited as a cause of 40 percent of aircraft accidents and 65 percent of air traffic delays. One reason the weather is so dangerous is the traditional lack of accurate and timely information provided to the pilots.

Presently, pilots and controllers rely on raw radar returns, surface or pilot observations, and their own experience to interpret weather patterns and make operational decisions. A recent study (Phillips, 1993, as cited in Boyer & Wickens, 1994) has shown that the present system has limitations in both safety and effectiveness. On one hand, underestimating a weather situation can put aircraft and passengers at risk unnecessarily. On the other hand, error on the side of safety, such as avoiding marginal weather all together, can result in time delays and wasted fuel and airspace in the terminal area.

With the latest generation of supercomputers, newly installed weather observing systems, high speed data communications, and modern computer-generated graphics, it is now possible to present weather forecast information in a format that meets user's needs (U.S. GAO, 1993). The integration and presentation of the weather data raises the question of which type of display should be used – 3D or 2D.

It might seem that a 3D rendering would be the natural choice to display weather data. After all, weather is a 3D phenomenon and the information in all three axis must be integrated in order to comprehend fully the weather constraints.

Nevertheless, research results did not show evidence that pilots perform better with the 3D display. In fact, the statistically significant results showed that the 2D displays enabled superior performance (Figure 4, 5). Also, in an informal debrief, the pilots preferred the 2D view.

Guidelines

Traffic Display:

- There have been some encouraging studies regarding 3D displays utilizing depth cues (ref. 6,9). However, the existing data do not support the recommendation of a 3D display for traffic information.
- A coplanar 2D display is recommended for the display of traffic information.

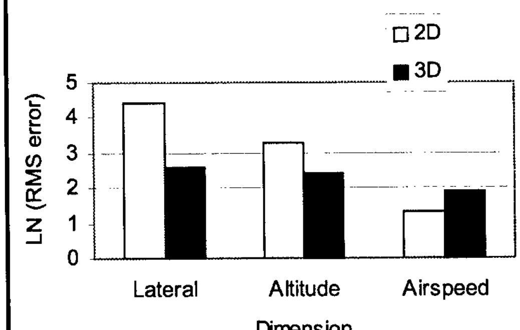

Figure 3. Flight path tracking accuracy for control with 2D and 3D displays.

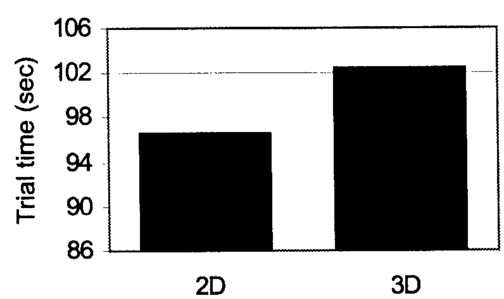

Figure 4. Time to complete trial for each display.

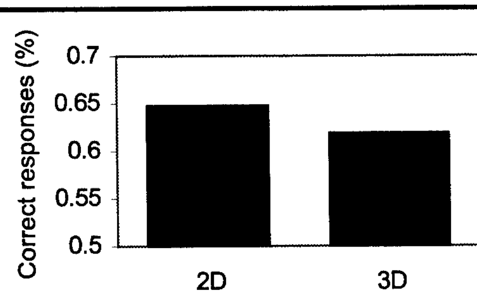

Figure 5. Percent of situation awareness questions answered correctly by pilots.

Navigation Display:

- Consider including a 3D ADI that incorporates command path boxes and an aircraft predictor.

Weather Display:

- 2D displays are recommended for the display of weather information.
- A planar view simultaneously displayed with a profile view is recommended for the display of weather information.

Constraints

Traffic Display:

- The 2D display must be a coplanar display. The single 2D display leads to poorer performance than the coplanar display.
- The 3D perspective display did not have depth cues (ref. 2,4,7)

Navigation Display:

- The display used in the experiment (ref 2) was a hybrid of the Attitude Director Indicator (ADI) and the navigation display.
- Widely varying navigational screens were used (ref 1, 5).
- Only landing approaches were flown (ref 5).

Weather Display:

- Student pilots were used (ref. 8).
- The sole task was to navigate around a weather problem (ref. 3).
- Subjects simulated ATC with the task of vectoring an aircraft around a weather formation (ref. 8).

Key References

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Bemis, S., Leeds, J. & Winer, E. (1988). Operator Performance as a Function of Type of Display: Conventional versus Perspective. *Human Factors*, 30(2), pp. 163-169.

Boyer, B. & Wickens, C. (1994). *3D Weather Displays for Aircraft Cockpits*. ARL-94-AA/NASA-94-4. NASA Ames Research Center. Moffett Field, CA.

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Mazur, K. & Reising, J. (1990). The Relative Effectiveness of Three Visual Depth Cues in a Dynamic Air Situation Display. *In Proceedings of the Human Factors Society 34th Annual Meeting*, pp. 16-20. Santa Monica, CA: HFS.

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Zenyuh, C., Reising, J., Walchli, S. & Biera, D. (1988). A Comparison of a Stereographic 3-D Display versus a 2-D Display. In *Proceedings of the Human Factors Society 32nd Annual Meeting*, pp. 53-57. Santa Monica, CA: HFS.

Component Arrangement

Background

Cockpit display components must be arranged within some physical space. "Ideally, each component would be placed in such a way as to optimize the ability of that component to serve its purpose. This optimum location would be predicted from [task requirements], human capabilities and characteristics, and would facilitate performance of the activities carried out in that space" (Sanders & McCormick, 1993).

Unfortunately, it is usually not possible to place each component in its optimum location. Tradeoffs are required.

These design tradeoffs concern not only the physical layout of the various displays, but also the arrangement of the information and menu choices within a multi-function display (MFD).

Sanders and McCormick (1993) describe four principles that can be used to help aid the designer.

1) *Importance Principle*: This principle states that important components be placed in convenient locations. Importance refers to the degree to which the component is vital to the achievement of the system objectives. The determination of importance usually is a matter of judgement made by experts (i.e. users) in the system operation.
2) *Frequency-of-Use Principle*: This principle states that frequently used components be placed in convenient locations.
3) *Functional Principle*: This principle provides for the grouping of components according to their function, such as the grouping of displays that are functionally related in the operation of the system.
4) *Sequence-of-use principle*: In the use of certain systems, sequences or patterns of relationship frequently occur in the operation of tasks. In applying this principle, the items would be arranged to take advantage of such patterns.

General Description

In putting together the various components of a system, no single principle can, or should, be applied consistently across all situations.

The notions of "importance" and "frequency" are particularly applicable to the basic phase of locating components in a general area. The "sequence-of-use" and "functional" principles tend to apply more to the arrangement of components within a general area (Sanders, McCormick, 1993).

One study found that, if the operational requirements actually do involve the use of the components in consistent sequences, then the "sequence-of-use principle" should be followed (Figure 1).

Guidelines

The four design principles described above should be applied to the design of MFD menus, but only on the basis of rational judgement, following the human-centered design philosophy. There is little empirical evidence that specifically supports these design principles.

If the operational requirements are such that the components or selections are used in a consistent sequence, then the sequence-of-use principle is recommended.

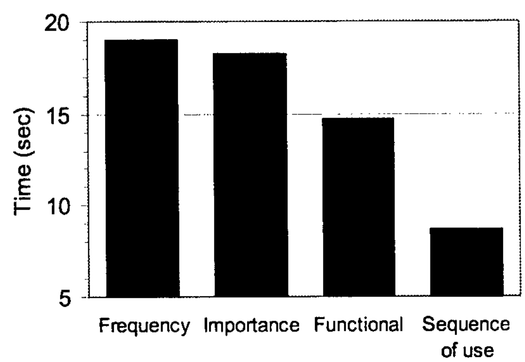

Figure 1. Time required to carry out tasks (in rather consistent sequences) with displays arranged on the basis of four principles.

Constraints

- There has not been a significant amount of research in this area.
- The experimental task used in the research may not adequately emulate cockpit tasks.
- The test subjects were students, not pilots. (ref 1).

Key References

1. Fowler, R., Williams, W., Fowler, K., and Young, D. (1968). *An investigation of the relationship between operator performance and operator panel layout for continuous tasks* (Tech. Rept. 68-170). U.S. Air Force AMRL (AD-692 126). Wright-Patterson Air Force Base, OH.
2. Kochhar, D. and Barash, D. (1987). Status displays in automated assembly. *Applied Ergonomics,* 18(2), pp. 115-124.
3. Sanders, M., and McCormick, E. (1993). *Human Factors in Engineering and Design.* McGraw-Hill Inc. 456-482.
4. Sargent, T.A., Kay, M.G., and Sargent, R.G. (1997). A Methodology for optimally Designing Console Panels for Use by a Single Operator. *Human Factors*, 39(3), 389-409.

Screen Layout

Background

An important design issue for MFDs is the simultaneous but separate presentation of displays. It may be desirable to allow more than one display to be presented simultaneously. That is, when the pilot selects a new display, it does not take the place of the current display but may go into a quadrant of the screen, allowing up to four displays to be shown at once. In addition to the partitioning of the display, there is also the concern of how to organize the fields within a display.

General Description

Boff and Lincoln (1988) have compiled a collection of guidelines to aid in screen layout and structuring that can also be applied to the design of MFDs.

Guidelines

- The user should be permitted to divide the screen into windows of appropriate size.
- Dashed lines may be used to segment the display.
- The unused areas should be used to separate logical groups, rather than having all the unused area on one side of the display.
- In data entry and retrieval tasks, the screen should be functionally partitioned into different areas to discriminate among different classes of information for commands, status messages, and input fields.
- To enhance important or infrequent messages or alarms, they should be placed in the central field of vision relative to the display window.
- The organization of displayed fields should be standardized. Functional areas should remain in the same relative location on all frames. This permits the users to develop spatial expectancies.
- Data should be arranged in logical groups: sequentially, functionally, by importance or by frequency.
- Logically related data should be clearly grouped and separated from other categories of data.
- Data should be arranged on the screen so that the observation of similarities, differences, trends, and relationships is facilitated for the most common uses.
- In computer-initiated dialogues, each display page should have a title that indicates the purpose of the page.
- In data entry and retrieval tasks, the last four lines on each display page should be reserved for messages, to indicate errors, communication links, or system status.
- Only required information should be displayed to avoid information overload or display clutter. The additional information should be available upon request.

Constraints

- These guidelines were not generated specifically for MFDs.
- These guidelines may be based accepted practices rather than empirically validated research.

Key References

Boff, K. & Lincoln, J. (1988). Screen Layout and Structuring in Person-Computer Displays. In *Engineering Data Compendium: Human Perception and Performance,* Section 11.332. AAMRL, Wright-Patterson AFB, OH.

Brown, C., Burkleo, H. Mangelsdorf, J., Olsen, R., & Williams, A., Jr. (1981). *Human factors engineering criteria for information processing systems.* Sunnyvale, CA. Lockheed.

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Pictorial Displays

Background

Technological advances have enabled designers to present information in the form of color pictures and schematics that can be rapidly changed and updated under software control. This capability may allow for the integration into one display of information distributed across several instrument readings and dozens of abstract symbols with alphanumeric codes (Stokes, Wickens, & Kite, 1990).

"Pictures and pictorial schematics can condense information into readily recognized 'Gestalts' in which the interrelationships between the data become much clearer" (Stokes, Wickens, & Kite, 1990). The picture is able to display the data in a way that is compatible with the pilot's mental model of the system.

The incorporation of pictorial displays also follows the display principle of pictorial realism. "The objective of which is to make the static representation of aviation displays conform as much as possible to the real-world configuration of the displayed item" (Stokes, Wickens, & Kite, 1990).

Many of the modern glass cockpits provide synoptic or summarizing diagrams of the various aircraft subsystems. With the increased power and speed of the on-board computers, it is expected that the number of schematics that the pilot can choose via the MFD will grow rapidly.

General Description

There is evidence that a redundant combination of pictorial and verbal information leads to a better understanding than either text or illustration on its own. Pictorial schematics that are unfamiliar and have no explanatory text are no more effective than text alone.

In general, pilots favor color pictorial formats – except when presented in a head-up display. Performance has been found to be better with the color displays.

Research also has revealed that the color pictorial is most effective when the display presentation is of short duration, or if the task was either complex or required that the pilot mentally recall an earlier screen (Stokes, Wickens, & Kite, 1990).

Guidelines

- Pictorial displays should be used whenever possible for the presentation of subsystem data.

Constraints

- It is somewhat unclear exactly what portion of the benefits of color pictorial displays result from the use of color.
- Some studies did not find any advantage with the pictorial displays. The merits of presenting specific information in a pictorial format should be considered.

Key References

Hawkins, J., Reising, J., & Gilmour, J. (1983). Pictorial format display evaluation. In *Proceedings of the National Aerospace and Electronics Conference 1983*, pp. 1132-1138. New York: IEEE.

Stokes, A., Wickens, C., & Kite, K. (1990). *Display Technology Human Factors Concepts*. University of Illinois Aviation Research Lab. SAE, Inc.

Stollings, M. (1984). *Information processing load of graphic versus alphanumeric weapon format displays for advanced fighter cockpits*. U.S. Air Force Flight Dynamics Lab, Wright-Patterson Air Force Base, OH. Tech report AFWAL-TR-84-3037.

Design of Icons and Symbols

Background

The designer of display icons or symbols must ensure that the icons convey the intended information in combination with other related symbols that may appear.

As flight decks become more information intensive, the difficulty of properly designing the icons increases. As Pejtersen and Rasmussen (1997) put it, "The possibilities concerning the design of icons are enormous and there are no rules or guidelines for making the best (or avoiding the worst) selection."

Like other issues in display design, specific guidelines will not lead the designer to an optimal solution. Success comes from a combination of general guidelines and a structured design approach early in the development cycle.

General Description

The SAE Committee G-10 has produced an aerospace standard titled "Human Interface Design Methodology for Integrated Display Symbology" (see ref 1). The document outlines a recommended approach for the design of integrated display symbology in support of flight tasks.

Guidelines

- Common symbology should be avoided for tasks that require different responses. The likelihood of operator error in this situation increases dramatically, especially if the task elicits a skill-based behavior. Even when appropriate training has been provided, high stress situations are often characterized by operator reversion to previously learned, and now incorrect, behavior.
- The designer must establish clearly that the information encoding of any standard symbology is both necessary and sufficient to support the intended task.
- Where the importance of the information warrants, the information should be encoded using two or more symbol attributes (e.g., color, size, and shape).
- Care must be taken to ensure that symbol attributes that have strong attention getting value (e.g., flashing color) are used sparingly and only when justified by the relative priority of the top-level task in relation to all of the user's other tasks.

To ensure compatibility with a wide range of end-user individual differences, multiple test subjects should be used to evaluate the symbology.

Constraints and Comments

- When applying this design process, consideration should be given to the more "general" user-centered design approach (ref 3).

Key References

Aerospace Recommended Practice. (1988). *Human Interface Design Methodology for Integrated Display Symbology.* ARP 4155. Society of Automotive Engineers, Inc.

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Rubin, J. (1994). The problem of unusable products and systems. In *Handbook of Usability Testing.* Wiley and Sons, Inc. pp. 3-46.

Icons: Complexity and Concreteness

Background

"The visual metaphor lies at the heart of modern graphical user interfaces. The benefits ascribed to its use rest largely on the belief that pictorially realistic icons allow users to apply pre-existing world knowledge to the display domain" (Curry, McDougall, & de Bruijn, 1998). These metaphors aim to capitalize on correspondences that exist between real world objects and representations of those objects.

The term "concreteness" refers to the "degree of pictorial resemblance that an icon has to its real-world counterpart" (Curry, McDougall, & de Bruijn, 1998). "When icon concreteness is high, parallels with the real world enable users to form expectations that can guide their use of the system" (Curry, McDougall, & de Bruijn, 1998). The drive towards using visually realistic icons can be counter-productive if it increases the level of visual complexity.

Design guidelines mention that icons should be kept as simple as possible (Easterby and Zwaga, 1984). Does an icon have to be complex in order to be concrete?

General Description

Complexity of icons can be accurately measured by adding the number of horizontal, vertical and diagonal lines, arcs, arrowheads, letters and special characters they contain (Garcia, Badre & Stasko, 1994). Complexity is not necessarily related to concreteness. A visual metaphor can be conveyed without having to add complexity.

Concreteness significantly affected accuracy and response times, while complexity had no effect. An icon does not have to be complex to be concrete.

Guidelines

- Icons should be kept as simple as possible and as concrete as possible. The visual metaphor makes the icons effective; complexity by itself adds nothing.

Constraints

- The benefits of the visual metaphor may fade for icons in regular use.
- Complexity may have to be added to obtain the desired concreteness.

Key References

1. Curry, M., McDougall, S. & De Bruijn, O. (1998). The Effects of the Visual Metaphor in Determining Icon Efficacy. In *Proceedings of the Human Factors Society 42nd Annual Meeting,* pp. 1590-1594. Santa Monica, CA: HFS.

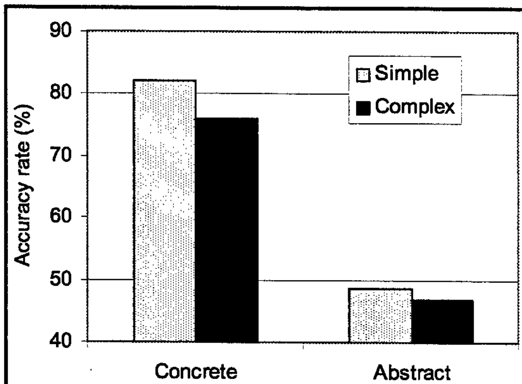


Figure 1. Accuracy rates for icon characteristics.

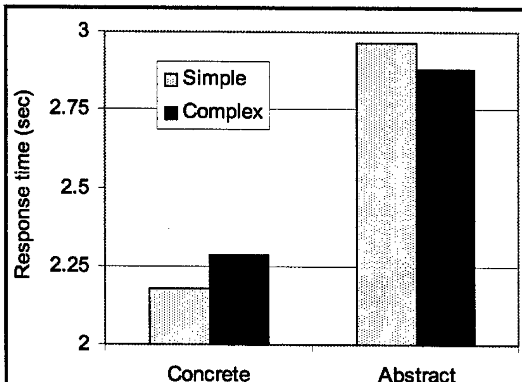


Figure 2. Response times for icon characteristics.

2. Easterby, R. & Zwaga, H. (1984). *Information design: The design and evaluation of signs and printed material.* Cichester: Wiley and Sons Ltd.

3. Garcia, M., Badre, A., & Stasko, J. (1994). Development and validation of icons varying in their abstractness. *Interacting with Computers*, 6, pp. 191-211.

4.7 General Design Principles for Aircraft Displays

The Principle of Pursuit Tracking

Background

"In many aircraft steering displays, the pilot's task is to track and null a computed steering error indication" (Roscoe, 1968). Such a task is not only required in both air-to-air and air-to-surface weapon delivery for military aircraft, but also in flying ILS landing approaches for commercial aircraft (Roscoe, 1968).

In most cases, "the displayed indications tell the pilot nothing about what their aircraft is doing or what the target is doing, but merely the differences between the two" (Roscoe, 1968). If these differences are nulled, the aircraft will be on the desired flight path. These displays typically present the error indications by means of a single moving element (i.e. a pair of cross-pointer indices that show the horizontal and vertical components of the error). These types of displays are known as compensatory tracking displays (Roscoe, 1968).

These compensatory displays could be modified in such a way, however, so that the target and the representation of the ownship both move independently against a common coordinate system. These types of displays are known as pursuit displays because the pilot's task is to cause the ownship symbol to pursue the independently moving target symbol (Roscoe, 1968).

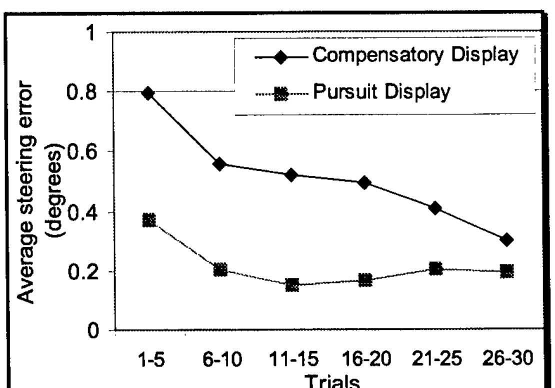


Figure 1. Comparison of pursuit and compensatory displays.

At present, the majority of pursuit displays are found in military applications, advances in technology may quickly change that. Global Positioning System technology has the potential to revolutionize aircraft landing procedures. It will enable pilots to fly complex, curved approaches rather than the more simple straight-in approaches necessitated by ILS. Navigational aids are being designed to assist the pilot's with this task. Examples include pathway and tuc:nnel displays incorporated into either a modernized Primary Flight Display (PFD) or into a separate display. Important human factors design issues are associated with how to present the desired flight path to the pilot.

General Description

Considerable experimental evidence indicates that tracking performance is significantly improved with the use of pursuit displays. Studies comparing the steering errors found with compensatory and pursuit have found approximately a two-to-one difference favoring the pursuit display. Discussions elsewhere in this report have indicated the advantage of portraying ownship as the moving part (e.g. the principle of the moving part and the frequency-separated attitude display). This principle is extended here. Performance is improved when the goal of desired performance (e.g., target symbol or command indication) also moves independently against the same external reference system (Roscoe, 1968).

Guidelines

- Pursuit rather than compensatory displays are recommended for tracking tasks. That is, the pilot's aircraft and the target symbol or command indication should both move independently against the same reference system.

Constraints

- Modern pathway or tunnel displays were not tested in these studies.

Key References

Bauerschmidt, D., & Roscoe, S. (1960) A comparative evaluation of a pursuit moving-airplane steering display. *IRE Trans. Human Factors in Electronics, HFE-1(2)*, pp. 62-66

Roscoe, S. (1968). Airborne Displays for Flight and Navigation. *Human Factors*, 10(4), 321-332.

Roscoe, S. (1980). Controls and Displays in *Aviation Psychology*. Iowa State Univ. Press, pp. 33-124.

The Principle of the Moving Part

Background

The question of whether the part of the display that represents the aircraft should move against a fixed scale or whether the coordinate system should move against a fixed index representing the aircraft, has long been a controversial subject in display design (Roscoe, 1968). As more information is available from multiple sources, and as the space within the displays becomes a more valuable commodity, it becomes more tempting to incorporate a moving scale with a fixed index of the aircraft, thus saving space that would be used to display the entire scale.

This design decision manifests itself in many separate issues. For example, as Roscoe (1968) describes:

1) Heading – should the compass rotate against a fixed line so that heading can always be read at the top of the display, or should a pointer rotate relative to a fixed compass so that the display movement is clockwise when the aircraft is turning right and vice versa?
2) Altitude – should altitude be represented by one or more pointers moving against a fixed altitude scale or should a moving scale be read against a fixed line index?
3) Attitude – should the horizon bar move against a fixed aircraft symbol or should the aircraft symbol move against a fixed outside world?

General Description

"There is an impressive body of experimental and operational evidence that the part of the display that represents the aircraft should move rather than the scale" (Roscoe, 1968). The results are so consistent that Roscoe (1968) has described this as a design principle (i.e. "the principle of the moving part").

:The simple explanation as to why the aircraft should move and not the scale or environment is that when pilots move the controls of their aircraft, they expect the aircraft and the aircraft symbol to not only move, but to move in the same direction as the control movement. The pilot "intuitively" expects the display to function this way.

Another advantage with the fixed scale is that the pilot can "immediately get a good deal of approximate information from looking at the display without reading the scale numbers. This is particularly important if the information is required for a quick check reading" (Roscoe, 1968) or if it needs to be integrated with other information that maybe stored in short term memory.

Although this research is old and much of it was conducted with "uni-functional" displays, the results are relevant to the design of modern cockpits. Today's designers are less constrained by technology and do not have to present the entire scale or compass or airspeed dial. They now have the tempting option of presenting only the current value of the indicator, which can easily lead them into designing a poorer interface.

Guidelines

- Adherence to the "principle of the moving part" is recommended. Specifically, whichever part of the display represents the aircraft should be the moving part as opposed to the scales or environment.

Constraints

- For cases when the exact "quantity" is required of the display, either a digital readout of the values can be added or a moving scale with clearer gradations may be needed.

Key References

1. Christensen, J. (1955). *The importance of certain dial design variables in quantitative instrument reading.* USAF: WADC TR pp. 55-376.
2. Roscoe, S. (1968). Airborne Displays for Flight and Navigation. *Human Factors*, 10(4), pp. 321-332.
3. Roscoe, S. (1980). Controls and Displays in *Aviation Psychology*. Iowa State Univ. Press, pp. 33-124.

Proximity Compatibility Principle

Background

"Indicators or displays in an aircraft are rarely presented in isolation. The sheer number of indicators can lead to clutter, increased information access cost, and in extreme situations, information overload" (Wickens & Carswell, 1997). To understand how the operator deals with this wealth of information, we must consider how we routinely combine sensory elements to form the higher-order entities we call groups. This concerns the problem of perceptual organization.

The "Proximity Compatibility Principle" deals specifically with the issue of display organization (Barnett & Wickens, 1988). In general, the principle holds that those "indicators or displayed data values that are conceptually related or that need to be used in combination should belong to the same perceptual group. In short, related information should be perceptually proximate" (Wickens & Carswell, 1997).

In order to group similar displays, similarity must be defined. This display "relatedness" or similarity is composed of task, correlational, system, and integration relatedness. Wickens and Carswell (1997) further describe these types of similarity as follows:

1) *Task relatedness*: Degree to which information in two displays must be used together to complete a task.
2) *Correlational relatedness*: Degree to which changes in the information in two displays are correlated over time.
3) *System relatedness*: Similarity of the systems underlying the two displays.
4) *Integrated Relatedness*: This measure is similar to task proximity, but involves displays of information that the user must integrate.

General Description

When the task requires a large amount of integration, performance decreases as the distance of the data to be integrated is increased (Figure 1). The distance described here is not necessarily a physical (or metric) distance, but a psychological or perceptual distance. The psychological distance can be manipulated. For example, the needed items can be enclosed in a box.

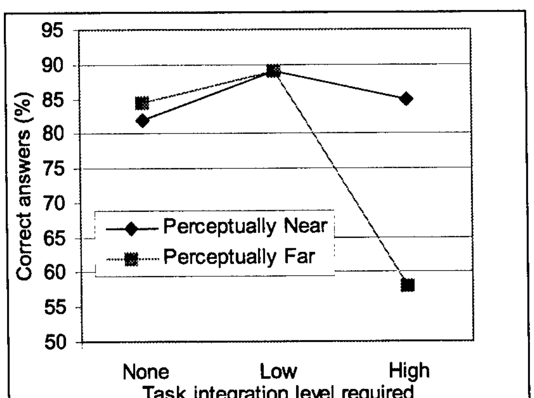


Figure 1. Perceptually proximate data presentation as a function of the integration required within the task.

Guidelines

- In general, displays or items that are related (per the four types of relatedness) should be grouped together.
- In general, displays or items that must be integrated, should be grouped together.

Constraints

- The research providing the basis for these guidelines was not conducted in an aviation setting.
- Tradeoffs must be considered between "relatedness" and other principles such as frequency-of-use and sequence-of-use.

Key References

1. Barnett, B. & Wickens, C. (1988). Display Proximity in Multicue Information Integration: The Benefits of Boxes. *Human Factors,* 30(1), pp. 15-24.
2. Vincow, M. & Wickens, C. (1992). *Space and the Proximity-Compatibility Principle: Traditional and Computational Models Approaches to Displayed Information.* ARL-92-7/ NASA A3I-92-2. University of Illinois at Urbana-Champaign Technical Report. Aviation Research Laboratory.
3. Wickens, C. & Carswell, C. (1997). Information Processing. In G. Salvendy, Ed., *Handbook of Human Factors and Ergonomics.* New York: Wiley and Sons, Inc. pp. 89-129.

Emergent Features

Background

"Emergent features are relational properties of a group of display elements that are not properties of any of the elements in isolation" (Pomerantz, 1981). "These emergent features are often rapidly detected by the user. For example, a series of vertical, moving-pointer displays that are placed side by side may produce the emergent feature of pointer alignment" (Wickens & Carswell, 1997). In this way, the detection of the emergent feature provides a shortcut to the reading of each individual pointer and the effortful task of checking each value. Note that if the indicators were "not exactly the same in scale design, had different baselines, or were located at distant parts of the display panel, then alignment would not be available to use as a cue" (Wickens & Carswell, 1997).

Another way to create emergent features is through the creation of object displays. "Object displays include any arrangement of elements that make the different data values appear to be part of a single perceptual object" (Wickens & Carswell, 1997). For instance, lines or contours can be added directly between data-varying dimensions (i.e. line graphs). Multiple indicators can be arranged so that the addition of line segments creates a closed object (Beringer, Howard, & Jenkins, 1986, Wickens & Carswell, 1997).

Examples of object displays include polygon-polar diagrams, box displays, and other multidimensional object displays. A row of parallel bar graphs, clustered ordering of different colors, or 3D contours for example, can all create emergent features and facilitate information integration tasks (Wickens & Carswell, 1997).

Designing with emergent features in mind is an example of how the designer can capitalize on a human perceptual characteristic. Visual processing of attributes of a single object is parallel and obligatory. It is parallel because people pay attention to all the dimensions or attributes at once. It is obligatory because people have no control over the process – one cannot notice one dimension or attribute of an object but ignore the others (Wickens & Carswell, 1997).

General Description

It is not an easy task to represent variables as emergent features that highlight the critical data relationships (Bennett et al, 1993). Decisions must be made concerning which variables should be included in the graphic form, how they should be assigned dimensions, whether they should be converted to common scale, and how to represent the task context. In addition, the application of emergent features requires a detailed understanding of the tasks for which the display will be used.

Studies have found that as the task becomes more integrated, the value of salient emergent features increases (Figure 1). Similarly, if the task remains a focused task in which individual data points are not integrated, the application of emergent features is of less use (Figure 2).

Guidelines

- If data values must be integrated, or are related functionally or conceptually, then emergent features should be exploited if possible.

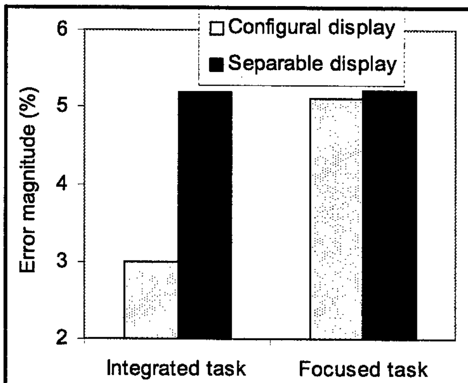


Figure 1. Errors for different tasks using different display designs (configural display has more salient emergent features).

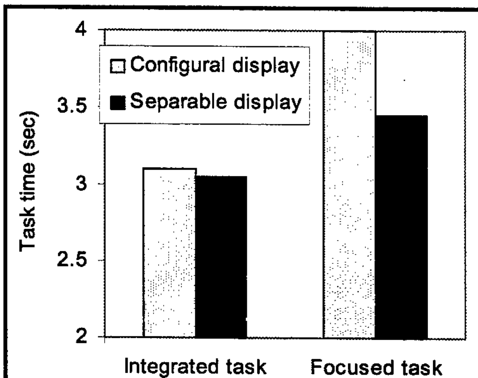


Figure 2. Completion time for different tasks using different display designs (configural display has more salient emergent features).

Constraints and Comments

- Because the application of emergent features is task-dependent and display-dependent, it is not always feasible.

Key References

Bennett, K., Toms, M., & Woods, D. (1993). Emergent Features and Graphical Elements: Designing More Effective Configural Displays. *Human Factors*, 35(1), pp. 71-97.

Beringer, D., Howard, F. & Jenkins, J. (1986). Putting Information in the Visual Periphery: It beats a Pointed Stick in the Eye. In *Proceedings of the Human Factors Society 30th Annual Meeting*, pp. 613-617. Santa Monica, CA: HFS.

Pomerantz, J. (1981). Perceptual organization in information processing. In M. Kubovy & J.R. Pomerantz, Eds., *Perceptual Organization* pp. 141-180. Hillsdale, NJ: Erlbaum.

Wickens, C. & Carswell, C. (1997). Information Processing. In G. Salvendy, Ed., *Handbook of Human Factors and Ergonomics.* New York: Wiley and Sons, Inc

Command and Status Displays

Background

Stimulus-response (S-R) compatibility has long been a "theme in the psychological literature since it was introduced by A.M. Small in a 1951 paper presented to the Ergonomics Research Society" (Andre & Wickens, 1992). "The concept was later popularized by Fitts and Seeger (1953) who showed that responses to corresponding stimulus and response sets was faster relative to less 'natural' arrangements" (Andre & Wickens, 1992).

The distinction between command and status displays can also be described in terms of S-R compatibility. For instance, a command display tells the operator what to do, and if the language of its command is motion, then it is S-R compatible (i.e. an upward display movement triggers an upward control movement). "The intention of this type of display is to negate the need to cognitively interpret the operational meaning of the display movement ('Am I too high? Too low?')" (Andre & Wickens, 1992).

"Some command displays, like the flight director of a modern aircraft for instance, provide the operator with direct advice regarding the direction of control" (Andre & Wickens, 1992). This format, however, bypasses a representation of the state for which the command is required. In effect, the command display "tells the pilot what to do without displaying the reasons why" (Andre & Wickens 1992).

On the other hand, "the status display provides the 'why' information, telling the operator what exists" (Andre & Wickens, 1992). The status display requires a corrective movement that is S-R incompatible (i.e. an upward display movement triggers a downward control movement). This type of display is similar to a compensatory tracking task and imposes an extra transformation (Simon, 1969).

The issue for cockpit display design is when to use command displays and when to use status displays.

General Description

Applied research findings reveal that status displays increase the accuracy of comprehending system states and, presumably, lead to a greater situational awareness (Figure 1). Consistency was found to be more important than whether the "appropriate" type of display was used (i.e. status or command)

Guidelines

- To promote situational awareness, individual displays should be "status" displays vice "command" displays.
- It is important to have consistency between the individual displays. If a command display is to be introduced, the form of it must be distinctly different from the status display so that there is little opportunity for confusion (e.g. the "climb, climb, climb" auditory warning on the TCAS).

Constraints

- There has not been a significant amount of research in this area.
- A relatively simple flight control task was used in this research.
- Vocal tasks as well as control tasks were analyzed. Some of the advantages with the status display were found to a larger extent with the vocal tasks.

Key References

1. Andre, A.D. & Wickens, C.D. (1992). Compatibility and Consistency in Display-Control Systems: Implications for Aircraft Decision Aid Design. *Human Factors*, 34(6), pp. 639-653.
2. Fitts, P., & Seeger, C. (1953). S-R compatibility: Spatial characteristics of stimulus and response codes. *Journal of Experimental Psychology*, 46, pp. 199-210.
3. Simon, S. (1969). Reactions toward the source of stimulation. *Journal of Experimental Psychology*, 81, pp. 174-176.

Displaying Uncertainty

Background

Few studies have addressed the issue of displaying the uncertainty of information presented in displays (Andre & Cutler, 1998). Rapid advancements in commercial avionics, integrated navigation tracking systems, and data link communications lead to an increased importance of information uncertainty (Andre & Cutler, 1998).

There are "proposed and expected changes to the structure of the National Airspace System that depend on the data presented to the pilots" (Andre & Cutler, 1998). "Free Flight" proposes an air space system whereby pilots have the authority to determine their own air routes without air traffic controller intervention" (Andre & Cutler, 1998). This concept depends on advanced situation awareness displays that can provide detailed information on other aircraft.

The uncertainty about the accuracy or reliability of the data presented to the pilots can lead to situation awareness problems. "As the pilot experiences both false alarms and misses due to both the existence and lack of representation of the data uncertainty, they may develop a lack of trust in, and eventual decrease in use of, the automated system" (Parasuraman & Riley, 1997, cited in Andre & Cutler, 1998).

Since there will be a mixed avionics equipage fleet for some time to come, there will be an issue of how to combine information with different levels of accuracy and timeliness on an integrated display (Johnson, 1998).

General Description

Little work has been done to evaluate and compare various techniques for displaying uncertainty. In addition to this, the issues of displaying the uncertainty of informational aspects other than aircraft position appear to be unexplored.

In navigation tasks, it was found that without uncertainty symbology, each increase in uncertainty was accompanied by an increase in the frequency of collisions and near misses. Thus, without a constant spatial reminder of the uncertainty, subjects either ignore or forget about it. Also, the graphical-explicit (ring around the icon) symbology was found to be superior to the text or graphical-implicit (color) symbology for displaying uncertainty (Andre & Cutler, 1998).

Guidelines

- When data uncertainty can affect safety, an indication of the level of data uncertainty should be displayed.

Constraints and Comments

- To date, there are not enough research studies to support any design recommendations for displaying uncertainty.

Key References

1. Amar, M., Vaneck, T., Chaudhry, A., & Hannon, D. (1995). A preliminary evaluation of electronic taxi charts with GPS derived position for airport surface situational awareness. *Proceedings of the 8th International Symposium on Aviation Psychology*, pp. 499-504.
2. Andre, A., & Cutler, H. (1998). displaying uncertainty in advanced navigation systems. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*. pp. 31-35. Santa Monica, CA: HFES.
3. Johnson, W. (1998). Issues and concerns in the design of cockpit displays of traffic information. In *Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting*. 40-41. Santa Monica, CA: HFES.
4. Parasuraman, R. & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39, pp. 230-253.

5.0 SAMPLES FROM EXISTING GUIDELINES OR STANDARDS

Boff and Lincoln (1988) Engineering Data Compendium

Abstract

The Boff and Lincoln (1988) compendium is a series of tools aimed at providing the data necessary for the human engineering design of crew systems. The compendium provides in-depth treatment of human perception and performance in terms of the variables that influence the human operator's ability to acquire and process information, and make effective decisions.

General Description

The three-volume compendium is an excellent source of information on a wide variety of human factors issues. A large section is dedicated to display interfaces. The following guidelines were based on information given in the display interfaces section of Boff and Lincoln (1988).

Sample Guidelines

Guidelines for Designing Alerting Signals.

1) Present high-priority alerting signals both visually and aurally. Maximize the probability of detection of each mode of the warning signal.

2) The detectability of high-priority visual alerting signals should be maximized as follows:
   a) Present visual alerting signals as close to the operator's line of sight as possible— maximum deviation of 15° for high priority alerts and 30° for lower priority.
   b) Visual alerting signals should subtend at least 1° of visual angle.
   c) Visual alerting signals should be twice as bright as other visual displays on the instrument panel.
   d) A visual alerting signal should be flashing against a steady background.
3) The detectability of auditory alerting signals should be maximized as follows:
   a) Auditory alerts should be multiple frequency with more than one frequency in the range of 250 to 4000 Hz.
   b) The amplitude of an auditory signal should be at least 15 dB above the amplitude of the masked threshold.
   c) An auditory alerting signal should be intermittent or changing over time.

Voice and Tone Warning Signals.

1) Voice warning signals should be incorporated for the situations in which reaction time is very important.
2) If multiple auditory alarms and a corresponding checklist are planned, consideration should be given to implementing a voice auditory warning system instead.
3) Making a verbal warning longer by including more words in the semantic condition does not improve response times; a keyword warning should be used.

Guidelines for the Use of Noncritical Auditory Signals.

1) An auditory signal should be used to alert and direct the user's attention to the appropriate visual display.
2) The optimum type of signal should be carefully evaluated, so that it is readily noticed by the user but not startling or interfering with others in the immediate area. Because of variable background noises, the intensity should be adjustable.
3) The intensity, duration, and source location of the signal should be compatible with the acoustical environment of the intended receiver as well as with the requirements of other personnel in the signal area.
4) Auditory signals should be intermittent, allowing the user sufficient time to respond. The signal should be automatically shut off by user response action.
5) Auditory signals should be triggered by system failures.
6) Non-critical auditory signals should be capable of being turned off at the discretion of the user.

Alarm Classification and Development.

1) Lessen the amount of alerts. Pilots report that there should be no more than four auditory alerts, and one preferred.
2) Alerts should be prioritized and each alert should carry information about how critical it is.
3) Non-critical alerts should not occur during periods of high workload; they should be delayed.
4) Alarms should be classified into categories in terms of their importance so that an appropriate warning system can be designed. The following classification is recommended:
   a) Warning – Requiring immediate attention and mandatory immediate response.
   b) Caution – Requiring immediate attention and rapid response.
   c) Advisory – Requiring general awareness of a marginal condition.

Clay (1993) DOT-FAA-93-18

Abstract

This report provides guidelines for the application of cognitive issues to the design of electronic instrument approach procedure (EIAP) displays. It presents 46 cognitive issues and 108 design principles. Its basic premise is that pilots need to be given unambiguous information as quickly and easily as possible in such a way that it can be understood and remembered until the time that it must be used. Recognition and discriminability of patterns, stress resulting from heavy workload, the effects of divided attention, and the need to take account of the pilot's expectations are discussed. The merits of color and size, paper and electronic display, and temporary removal of nonessential information are examined.

General Description

Key cognitive issues are described along with many guidelines to EIAP design. Sections include topics such as Perception and Cognition, Attention and Performance Limitations, Organization and Grouping of Information, and Dynamic Displays. Many of the guidelines are appropriate beyond EIAPs to MFD design generally.

Sample Guidelines

Perception and Cognition.

1) Eliminate any irrelevant information from the display.
2) Use redundant coding of targets (make targets different on more than one dimension – shape, size, color).
3) Make object features distinctive.
4) If a moving map is used, display symbols with an upright (track-up) orientation at all times.

Attention and Performance Limitations.

1) Locate frequently sampled information centrally.
2) Information items that are often sampled sequentially should be located close together.
3) Avoid presenting information in such a way that inappropriate information is more salient than appropriate information. Motion, color, highlighting, and size may make information more salient.

Organization and grouping of Information

1) Use task analyses to determine groupings of information that are meaningful for the task.
2) Minimize the number of codes that are used for grouping.

Dynamic Displays

1) Provide decluttering techniques that do not remove information completely.
2) A cue to what information is on hidden screens should be present at all times.

Department of Defense (1991) MIL-STD-411E

Abstract

The purpose of this standard is to establish uniform requirements and provide functional design criteria for an effective aircrew station alerting system. The use of new technology is encouraged where it can be demonstrated that the use of the technology will result in shorter aircrew response times and more effective aircrew action subsequent to presentation of the alert.

General Description

This standard gives descriptions of the requirements for alerting systems within aircraft.

Sample Guidelines

- **Warning signals. Advisory signals.** The use of advisory signals in the cockpit area shall be minimized to avoid unnecessary distraction of the aircrew and to minimize factors that compromise the night vision capability of the crew.
- **Integrated alert displays. Number and location of displays.** The number of displays shall be based upon the informational requirements of the aircrew and the reliability of the displays. All warning, caution and advisory messages shall be presented within the operator's 30-degree forward cone of vision, on a single display surface, insofar as practical. If more than one display is present at a crew station, the display farthest to the left should display all warning, caution, and advisory messages.
- **Message format. Color coding.** When color is used to provide a unique and easily distinguishable coding method for all three alerting categories, red shall be reserved for warning messages, yellow shall be reserved for caution messages, and a third color (green preferred with blue and white as non-flightdeck options) shall be used to represent advisory level messages.
- **Audio warning signals. Wheels-up signal.** When a nonverbal audio wheels-up signal is used, it shall have the following tone.
  a) Frequency = 250 ± 50 Hz.
  b) Fundamental tone interrupted at 5 ± 1 Hz.
  c) 50 ± 10 percent on-off cycle.

Department of Defense (1984) MIL-STD-783D

Abstract

This standard establishes the requirements for legends to be used for marking controls and displays in aircrew stations and on airborne equipment.

General Description

This standard gives recommended abbreviations (legends) for a large collection of terms that may be used in an aircrew station.

Sample Guidelines

Word	*Legend*
Absolute	ABS
Acceleration (Gravity)	G
Acquire	ACQ
Accumulator	ACC
Actuate	ACTU
Adjust	ADJ
Advantage	ADV
Afterburner	A/B
Aileron	AIL
Aircraft	ACFT
Airspeed	A/S
Alternate	ALTN
Alternator	ALTNR
Altitude	ALT
Ambient	AMB
Ampere	AMP
Amplifier	AMPL
Antenna	AMPTD
Armament	ANT

Department of Defense (1984) MIL-STD-1295A

Abstract

The purpose of this standard is to establish human factors design criteria for symbolic and alphanumeric information used on electronically and optically generated airborne displays. Electronically and optically generated displays are those in which an image is presented to the observer directly on the image-generating surface or indirectly through an optical projection system. The symbolic presentation provides flight, combat, and cargo-handling information with or without video imagery for rotary-wing aircraft. This standard is restricted to those display devices used in aircraft for the purpose of flight or mission control. Separate radar or electronic warfare displays are not included.

General Description

This document describes the general requirements for the information presentation of airborne electronic display elements. Although it is specifically for helicopters, much of the information and guidelines are applicable to aircraft displays in general.

Sample Guidelines

1) Information presentation characteristics.
2) Information presented by the displays shall be in symbolic, pictorial, or alphanumeric forms as specified by the procuring activity.
3) The meaning and motion of symbols shall be consistent throughout all modes of the display. Scaling and gain changes are permitted between modes.
4) The sense of aircraft control symbol motion should be compatible with the motions of the corresponding controller.

Head-up/helmet-mounted displays.

The HUD/HMD shall present all essential flight and mission information. All information reflected from the display shall be collimated and or sufficient brightness to be seen in a real-world background of 10,000 foot-candles illumination.

Department of Defense (1989) MIL-STD-1472D

Abstract

This standard establishes general human engineering criteria for design and development of military systems, equipment and facilities. Its purpose is to present human engineering design criteria, principles and practices to be applied in the design of systems, equipment and facilities to support the following objectives:

a) Achieve required performance by operator, control and maintenance personnel.
b) Minimize skill and personnel requirements and training time.
c) Achieve required reliability of personnel-equipment combinations.
d) Foster design standardization within and among systems.

General Description

This document provides requirements and recommendations concerning the design of a wide variety of military systems and equipment. In addition to sections on displays, there are sections on controls, labeling, anthropometry, and hazards and safety, to name a few.

Sample Guidelines

Visual Displays. Information.

Content. The information displayed to an operator shall be sufficient to allow the operator to perform the intended mission, but shall be limited to that which is necessary to perform specific actions or to make decisions.

Precision. Information shall be displayed only within the limits and precision required for specific operator actions or decisions.

Redundancy. Redundancy in the display of information to a single operator shall be avoided unless it is required to achieve specific reliability.

Audio Displays. Audio warnings.

Audio signals shall be provided, as necessary, to warn personnel of impending danger, to alert an operator to a critical change in system or equipment status, and to remind the operator of a critical action or actions that must be taken.

Touch-screen controls for displays.

Touch-screen control may be used to provide an overlaying control function to a data display device such as CRTs, dot matrix/segmented displays, electroluminescent displays, programmable indicators, or other display devices where direct visual reference access and optimum direct control access are desired.

Department of Defense (1996) MIL-STD-1472E

Abstract

This standard establishes general human engineering criteria for design and development of Military systems, equipment and facilities. Its purpose it to present human engineering design criteria, principles and practices to be applied in the design of systems, equipment and facilities so as to: a) Achieve required performance by operator, control and maintenance personnel. b) Minimize skill and personnel requirements and training time. c) Achieve required reliability of personnel-equipment combinations. d) Foster design standardization within and among systems.

General Description

This design standard includes specifications and guidelines for a wide range of systems and subsystems. A sample of the section titles reveals such varied topics as control/display integration, light-emitting diodes, design of labels, and anthropometry.

The section on visual display is concerned more with physical dimensions of displays, rather than design guidelines, and are of limited help within the scope of this project. The proper illumination, reflection, and lines of sight are typical concerns that are addressed in this section.

Sample Guidelines

- **Visual displays. Display illumination. Normal.** When maximum dark adaptation is not required, low brightness white light shall be used; however, when maximum dark adaptation is required, low luminance (.07-.35 cd/m2) red light (greater than 620 nm) shall be provided.
- **Visual displays. Information. Content.** Information displayed to an operator shall be sufficient to allow the operator to perform the intended mission, but shall be limited to information necessary to perform specific actions or to make decisions.
- **Visual displays. Location and arrangement. Vibration.** Vibration of visual displays shall not degrade user performance below the level required for mission accomplishment.

Workspace design. Seating. Cushioning and upholstery. Where applicable, both the backrest and seat shall be cushioned with at least 25 mm of compressible material and provided with a smooth surface. Upholstery shall be durable, nonslip, and porous.

Department of Defense (1996) MIL-STD-1787B

Abstract

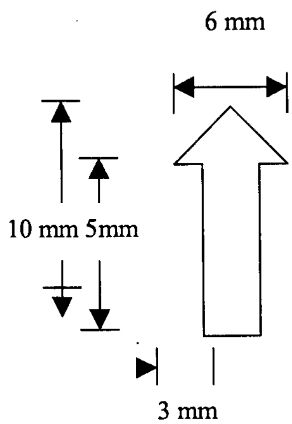
This standard describes symbols, symbol formats, and information content for electro-optical displays that provide aircrew members with information for takeoff, navigation, terrain following/terrain avoidance, weapon delivery, and landing. It describes symbol geometry, font, recommended dimensions, and mechanizations. This document also defines the symbology requirements for a primary flight reference and describes some fundamental relationships between symbol motion and aircraft system states.

General Description

This document gives the graphical requirements for the collection of symbols that appear on aircraft displays. The requirements are very specific for the individual symbols, describing the angles, dimensions, and thickness of all the symbology.

Sample Guidelines

Bearing pointer. The bearing pointer displays the relative bearing to the selected navaid station. The pointer shall be located 20 mm from the center of the bearing indicator and shall be free to rotate a full 360 degrees about the center. If the navaid is not receiving a signal from a station, then the pointer shall not display.



Department of Defense (1989) MIL-HDBK-761A

Abstract

The purpose of this handbook is to provide guidance in the application of human engineering to the design and development of management information software systems. The users of this document are intended to be any individual, or group, who participates in the development of software systems, including logicians, software engineers, end-system users, software development managers, programmers, system evaluators, and human factors engineers.

General Description

The first portion of this document contains a description of a recommended design process, a general approach to rapid prototyping, and a collection of human factors engineering design principles. The majority of the document contains detailed guidelines concerning the design of "systems that perform routine processing functions, but which are designed so that processing will produce information that will assist in decision making." Sample topic areas include labeling and terminology, data entry feedback, speech input, data display, flowcharts, and error feedback.

Sample Guidelines

Graphics. Maps and situation displays. *Format*

1) Orientation of maps and situation displays should be consistent or under user control.
2) When maps present large geographic areas, a consistent method of projecting the earth's curvature on a flat display surface should be specified and adopted.
3) Distance judgements from map displays should be supported through grid overlays, pointing devices, or other means.

Expert Systems. Graphic interface.

1) The expert system should have the capability to graphically represent its rules network. This capability should be available to the user as an adjunct to the explanation subsystem.
2) Graphics, such as a system schematic, should be used to depict relationships between system configuration and measurable parameters.
3) Graphics should portray system/ component/process status through the use of color, shading, or similar coding techniques.
4) Coding techniques should be consistently applied across the expert system.

Speech Output.

1) Computer-generated speech output may be used for guidance messages in environments with low ambient noise, when a users attention may not be directed toward a visual display, or when providing a visual display is impractical.
2) Computer-generated speech messages should be limited in number, distinctive from routine messages, short and simple.

Data Display. Display control.

1) Users should be able to tailor information displays by controlling data; selection coverage, updating, and suppression, and should be able to specify data for display. An easy means to return to normal display coverage should be provided.
2) Users should be able to control displayed data or enter new data when required by the task.

3) As required, users should be able to print paper copies of information displayed.
4) Users should not be required to remember data accurately from one display page to another.

Federal Aviation Administration (1994) AC 20-130A

Abstract

This advisory circular (AC) establishes acceptable means, but not the only means, of obtaining airworthiness approval of multi-sensor navigation or flight management systems integrating data from multiple navigation sensors for use as a navigation system for oceanic and remote, domestic en route, terminal, and non-precision instrument approach operations. This document does not address GPS equipment incorporating differential GPS capability. Like all advisory material, this advisory circular is not, in itself, mandatory and does not constitute a regulation. It is issued for guidance purposes and to outline one method of compliance with airworthiness requirements.

General Description

Much of the information in this circular concerns installation and evaluation of the navigation equipment. There is however, one section concerning the 2D accuracy requirements of the GPS sensor. These requirements are similar to those found in RTCA Document No. RTCA/DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning Systems (GPS)." (Listed later in section.)

Sample Guidelines

System Accuracy. 2D Accuracy Requirements (95 percent probability)

For equipment incorporating a Class B( ) or C( ) GPS sensor, the total position fixing error of the airborne multi-sensor equipment shall be equal to or less than that shown in the following table when GPS data is used in the position/navigation computation:

	position fixing	CDI centering
Oceanic & remote (nm)	.124	.20
en route (domestic) (nm)	.124	.20
Terminal (nm)	.124	.20
non-precision approach (nm)	.056	.01

Federal Aviation Administration (1987) AC 25-11

Abstract

This advisory circular (AC) provides guidance for certification of cathode ray tube (CRT) based electronic display systems used for guidance, control, or decision-making by the pilots of transport category airplanes. Like all advisory material, this document is not, in itself, mandatory and does not constitute a regulation. It is issued to provide guidance and to outline a method of compliance with the rules.

General Description

The material provided in this AC consists of guidance related to pilot displays and specifications for CRT's in the cockpit of commercial airplanes. The contents include sections on information separation, display visual characteristics, and information display, for example. Although the majority of the guidance concerns individual displays, there are some guidelines that can be useful for the design of a MFD.

Sample Guidelines

Information Display. Full-Time vs. Part-Time Displays. Some aircraft parameters or status indications are required by the FAR to be displayed, yet they may only be necessary or required in certain phases of flight. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to full-time display must be demonstrated. Criteria considered include the following:

1) Continuous display of the parameter is not required for safety of flight in all normal flight phases.
2) The parameter is automatically displayed in flight phases where it is required.
3) The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value.
4) Display of the inhibited parameter can be manually selected by the crew without interfering with the display of other required information.
5) If the parameter fails to be displayed when required, the failure effect and compounding effects must meet requirements.
6) The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered.
7) If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation.

Information Separation. Color Standardization

1) The following depicts acceptable display colors related to their functional meaning recommended for electronic display systems.

Item	*Color*
Warnings	Red
Flight envelope, system limits	Red
Cautions, abnormal sources	Amber
Earth	Tan/Brown
Scales /assoc. figures	White
Engaged modes	Green
Sky	Cyan/Blue
ILS deviation pointer	Magenta
Flight director bar	Mag./Green

2) Specified display features should be allocated colors from one of the following

Color Sets:	*Set#1*	*Set#2*
Fixed ref. symbols	White	Yellow
Current data	White	Green
Armed modes	White	Cyan
Selected data	Green	Cyan
Selected heading	Magenta	Cyan
Active route/Flt plan	Magenta	White

3) Precipitation and turbulence areas should be coded as follows:

Precip. *(mm/hr):*	***Color***
0-1	Black
1-4	Green
4-12	Amber/Yellow
12-50	Red
>50	Magenta
Turbulence	White or Magenta

Federal Aviation Administration (1996)

Abstract

Advances in technology have enabled increasingly sophisticated automation to be introduced into the flight decks of modern airplanes. Generally, this automation was added to accomplish worthy objectives such as reducing flightcrew workload, adding additional capability, or increasing fuel economy.

Vulnerabilities do exist, though, and further safety improvements should be made. As a result, the Federal Aviation Administration chartered a human factors team to address problems in design, training, flight crew qualifications, and operations, and to recommend appropriate means to address these problems.

General Description

This document is an excellent source for descriptions of usability problems that have been experienced in the modern cockpit and, to a lesser extent, a source for design recommendations. The various sections include Flightcrew Management, Situation Awareness, and Design Processes.

Much of the document describes the problems that need to be solved, and generally what needs to be done (e.g. The FAA should assure that analyses are conducted to better understand why flightcrews deviate from procedures). There is a lack, however, of specific design recommendations. Nevertheless, this document is a good source of general guidelines, which can be valuable in the design process.

Sample Guidelines

Automation Management. FMS design.

1) Critical or irrevocable entries should be confirmed before they are executed, as well as providing an "undo" capability when appropriate.
2) There is a need for standardization of route, leg, and constraint conventions such as waypoint entry conventions, definition, and implementation of vertical profiles in order to reduce error potential and facilitate easier transitioning between airplane types.

Automation Management. Flightcrew information.

1) The flightcrew should be provided with the manufacturer's higher-level design philosophy (e.g., the reasons for automating particular functions) to the extent that this philosophy could affect operational use.
2) The flightcrew should be provided with a description of the envelope of protection features, including specific capabilities and limitations, and the situations or flight conditions for which envelope protection is or is not available.

Flightcrew Situation Awareness

The FAA should sponsor research or assure that research is accomplished, to develop improved methods for evaluating designs for susceptibility to hazardous states of awareness.

Terrain Awareness

The FAA should encourage the aviation industry to develop and implement new concepts to provide better terrain awareness.

Federal Aviation Administration (1992) TSO-C129

Abstract

This technical standard order (TSO) prescribes the minimum performance standard that airborne supplemental area navigation equipment using the global positioning system (GPS) must meet in order to be identified with the applicable TSO marking.

General Description

This standard includes a collection of requirements that are in addition to, or in lieu of, the requirements in the RTCA document No. RTCA/DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)."

Sample Guidelines

Waypoint Storage.

1) The equipment navigation database shall also include all waypoints and intersections included in published non-precision instrument approach procedures.
2) The equipment shall store all waypoints, intersections, and/or navigation aids and present them in the correct order for a selected approach as depicted on published non-precision instrument approach procedure charts.
3) Waypoints utilized as a final approach fix or missed approach point in a non-precision approach shall be uniquely identified as such to provide proper approach mode operation.
4) The equipment shall provide the capability for entering, storing, and designating as part of the active flight plan a minimum of nine discrete waypoints.

Failure/Status Indications.

The equipment shall indicate, independent of any operator action, the following by means of a navigation warning flag on the navigation display.

1) The absence of power required for the navigation function.
2) Any probable equipment malfunction or failure affecting the navigation function.
3) Loss of navigation function.

NASA (1987) NASA-STD 3000

Abstract

This document provides specific user information to ensure proper integration of the man-system interface requirements with those of other aerospace disciplines. These man-system interface requirements apply to launch, entry, on-orbit, and extraterrestrial space environments. This document is intended for use by design engineers, operational analysts, human factors specialists, and other engaged in the definition and development of manned space programs.

General Description

This is a large, multi-volume work that contains design considerations, requirements and examples for manned space systems. Much of the work is not applicable to aviation displays. There are sections on displays, user-computer interaction, and information management that can be generalized to apply to MFD issues.

Sample Guidelines

User-Computer Interaction Design Considerations. Design Principles.

- Feedback, which is appropriate, rapid, and predictable, should be given for each user action.
- Required actions or commands should be easy to learn, and should follow some rational or logical sequence.
- It should be difficult to make mistakes and easy to recover from mistakes that are made.
- The design should allow the crewmembers to focus attention on the task rather than on what they have to do with the system to accomplish that task.

Display Content Design Requirements.
Information Density

- Information density shall be held to a minimum in displays used for critical tasks.

Feedback Design Requirements.

- *Use* – Clear and concise feedback shall be provided to users as necessary to provide status information throughout the interaction.
- *Source* – Feedback shall indicate actual function status.
- *Process Outcome* – When a control process or sequence is completed or aborted by the system, positive indication shall be presented to the user concerning the outcome for the process and the requirements for subsequent action.
- *User Input Rejection* – If the system rejects a user input, feedback shall be provided to indicate the reason for rejection and the required corrective action. The location of the problem shall also be indicated.

Nuclear Regulatory Commission (1996)
NUREG-0700

Abstract

NUREG-0700 provides human factors engineering guidance to the U.S. Nuclear Regulatory Commission staff for its:

1) review of the human system interface (HSI) design submittals prepared by licensees or applicants for a license or design certification of commercial nuclear power plants.
2) Performance of HSI reviews that could be undertaken as part of an inspection or other type of regulatory review involving HSI design or incidents involving human performance.
3) The guidance consists of a review process and HFE guidelines.

General Description

This guideline document contains hundreds of specific guidelines on topics such as Information display, User-System Interaction, Input devices, Alarms, and Workplace design. Although not specifically created for the aviation community, this document has many recommendations that are applicable to MFD design.

Sample Guidelines

User-System Interaction. Menu Selection.

- Return to Higher-Level Menus. Users should have to take only one simple key action to return to the next higher level in hierarchic menus.

Consistent Location for Menus.

- Menus should be displayed in consistent screen locations for all modes, transactions, and sequences.

User-System Interaction. Direct manipulation.
When to Use.

- Direct manipulation should be used primarily in tasks with actions and objects that lend themselves to pictographic representations and in which the actions and objects need not be modified for the successful interpretation of the command by the system.

Managing Displays. Display Selection and Navigation.

- **Sequential Steps on Multiple Displays.** When actions on a new display in a sequence require completion of actions on a previous display, the user should be able to move to the new display only when all of the conditions have been met or when an intentional override procedure has been confirmed.

NATO Standardization Agreement (1992)
STANAG 3705

Abstract

The participating NATO nations have agreed upon the human engineering design criteria for controls and displays in aircrew stations as detailed in this document.

General Description

This standard is a short collection of general control and display guidelines.

Sample Guidelines

Controls/Display Integration

1) *Relationship*. The relationship of a control to its associated display and the display to the control shall be immediately apparent and unambiguous to the operator.
2) *Design*. Control-display relationship shall be apparent through proximity, similarity of groupings, coding, framing, labeling, and similar techniques.
3) *Complexity and Precision*. The complexity and precision of control manipulation and display monitoring shall be consistent with the precision required of the system. Control/display complexity and precision shall not exceed the capability of the operator.

Controls. Selection

1) Multirotational controls shall be used when precision is required over a wide range of adjustment.
2) Detent controls shall be selected whenever the operational mode requires control operation in discrete steps.
3) Stops shall be provided at the beginning and end of the range of control positions.

Visual Displays. Information

1) The information displayed to an operator shall be limited to that which aids the performance of specific actions and the making of decisions.
2) Information shall be presented to the operator in a directly usable form. Requirements for transposing, computing, interpolating, or mentally translating into other units shall be avoided.
3) Failure of a display or its circuit shall be immediately apparent to the operator.
4) Signals and display information should have durations of sufficient length to be reliably detected under expected operator workload and operational environments.

RTCA (1991) RTCA Document No. RTCA/DO-208

Abstract

This document sets forth the operational goals and applications, and recommends standards and test procedures for airborne modes or any combination thereof. The report defines performances, functions, and features for 2D airborne equipment, which performs only lateral guidance, and 3D equipment, which performs both lateral and vertical guidance.

General Description

This standard contains many specific requirements for the RNAV and VNAV systems. The requirements include display accuracy limits, resolution requirements, TO-FROM equipment indications, waypoint entry and storage, and alarm limits.

Sample Guidelines

Equipment Performance Requirements.

Update Rate. A display update interval of 1.0 second or less shall be used.

2D RNAV Requirements.

Numeric display Information.

- For en route and terminal modes, the equipment shall provide a numeric display or electrical output of cross-track deviation to at least +/- 20 nm (left and right). A minimum resolution of 0.1 nm up to 9.9 nm beyond shall be provided. The display may be pilot-selectable.
- The display or output shall be accurate to within 0.3 nm up to 9.9 nm and 1.0 nm beyond or 2 percent of the actual cross-track, whichever is greater, referenced to a centered CDI display.
- If provided for approach mode, the display or output shall be accurate to within 0.1 nm, referenced to a centered CDI display.

VNAV Requirements. Waypoint Altitude.

The equipment shall provide a manual means of entering and storing an altitude directly associated with the active waypoint. The resolution of waypoint altitude entry shall be 100 ft or better for en route and terminal flight phases and 10 ft or better for the approach phase. This requirement shall be met over the altitude range as specified by the equipment manufacturer.

RTCA (1996) RTCA Document No. RTCA/DO-229

Abstract

This document covers GPS navigation augmented by Wide Area Augmentation System (WAAS) for en route, terminal, non-precision approach and preliminary requirements for a precision approach. The FAA's technical standard order (TSO) will only cover operations from en route to non-precision approach. The precision requirements are still being developed. This document addresses Beta, Gamma, and Delta functional classes. Compliance with these standards by manufacturers, installers, and users is recommended as one means of assuring that the equipment will satisfactorily perform it's intended functions under conditions encountered in routine aeronautical operations.

General Description

This is a wide-ranging and comprehensive standard concerning such topics as display symbology and installation and the design of control labels. This, along with the FAA's TSO (C-129), AC (20-130A), and RTCA document DO-208 all contain standards and requirements for GPS implementation. Many of the requirements are still being developed.

Sample Guidelines

Controls. Control labels.

Labels shall be readable from viewing distances of 30 inches, under anticipated lighting conditions. Labels shall be unobstructed by controls when viewed within the angle of regard, and located next to the controls that they reference. Label placement relative to controls should be consistent across the panel. Terminology for labeling should describe the function of the control in meaningful terms.

Controls. Equipment operating procedures.

The tasks shown in the following table shall be capable of being accomplished within the time indicated.

Task	Max # of: Actions	Max # of: Time (s)
Return to default navigation screen	1	2
Direct to any waypoint or approach already in flight plan	5	10
Select a course from a waypoint in flight plan	8	15
Initiation of the missed approach procedure	2	2
Repeat the previous approach	5	10
Initiate an approach in database	8	10
Selecting a vector-to-final to the approach	4	8

Society of Automotive Engineers (1969, reaffirmed 1991) AIR-1093

Abstract

Numerous variables influence the legibility of aircraft instrument dial characters. This situation makes it very difficult, if not impossible, to establish an exact set of rules for optimizing all installations. Character size, one of the important considerations, can be optimized where adequate dial space exists. Usually this is not the case and the designer is faced with placing the information in a limited space while continuing to strive for error-free legibility. Appropriate minimum size requirements have been stated herein for guidance in air transport use.

General Description

This relatively old document gives such information as the recommended minimum character height, width/height ratio, and stroke width/height ratio for dials and counters. The character size requirements also will apply to MFDs.

Sample Guidelines

Min. Char. Ht.	
Flat dials	In.
fixed	.150
moving	.200

Min. Char. Ht.	
Counters	In.
fixed	.187
moving	.250

Society of Automotive Engineers (1988) ARP-4032

Abstract

This document makes recommendations concerning human factors issues in the application of color to self-luminous display instrument systems. Although this document is specifically intended for the application of color to cathode-ray-tube (CRT) instrumentation, most portions are also compatible with other emerging electronic display technologies, whether they are self-luminous or light modulating devices, such as liquid crystal displays.

General Description

This document summarizes the research related to the use of color in displays. The topics include uses for color, number of colors, brightness, and color specification.

Sample Guidelines

Uses for Color. Alerting.

- Traditional warning and cautionary colors (red and amber or yellow) should be reserved solely for this purpose, as the use of these colors for other functions will degrade their alerting value.
- A single display device should not employ colors that are closely spaced on a chromaticity diagram as these will appear similar to one another and hence be difficult to discriminate among.
- For critical alerting functions, color should be redundant with other visual or auditory information coding methods.

Uses for Color. De-Cluttering.

Color can serve to group or organize information. This allows information to be transmitted more efficiently as long as the number of colors used for this purpose is limited. A large number of colors may actually be counter-productive to organizing information. The number of colors used on a single display should be kept to a minimum for the purpose of de-cluttering.

Uses for Color. Coding.

In general, color should not be used to code quantitative information unless that information can be divided into a small number of distinct categories such as has been done for color coded weather radar map displays.

Society of Automotive Engineers (1995) ARP-4033

Abstract

A pilot-system integration approach for concept development is recommended. The approach emphasizes the fundamental need for a top-down design methodology with particular focus on clear operational performance requirements and functional integration. The approach is derived from established human factors engineering design principles.

General Description

As was mentioned in the introduction of the present document, "no collection of guidelines exists, or can exist, that will be able to answer each of the unique questions that arise." This Aerospace Recommended Practice (ARP) document presents a human factors engineering design process that will establish a more disciplined design and integration methodology to improve the quality of the design recommendations.

The overall concept of Pilot-System Integration described in this document is very similar to the User-Centered Design process described earlier in the present document.

Sample Guidelines

This document offers a design process to achieve the following objectives:

1) Facilitate the matching of pilot skills to tasks required to operate the equipment in its environment.
2) Identify and sequence the human factors engineering tasks for each new and revised design.
3) Ensure consistency in human factors engineering processes and their outputs.
4) Facilitate customer involvement by providing customers with information on the nature of the human factors engineering tasks, their processes, output, and expertise.

Society of Automotive Engineers (1988) ARP-4102

Abstract

This document recommends criteria for the design, installation and operation of panels, controls, and displays on the flight deck or transport aircraft.

General Description

The majority of this document concerns the location and size of the overhead panel, instrument panel, and glareshield panel, and the operation of the controls. There is however, a three page section on displays that has some useful information on fault alerts and color (the color portion is a subsection of FAA AC 25-11. See Sample Guidelines within that citation).

Sample Guidelines

Displays. Fault Alerts.

- Individual fault alerts shall be provided for each display that is essential for continuation of flight in all flight phases.
- Alerts shall include mechanical and electrical malfunctions as well as loss of power or signal, which could result in a malfunction of the display. A distinction shall be evident between loss of signal and equipment failure.
- Attitude, navigation and air data systems should incorporate an alert for significant discrepancies between similar systems, and between sensed and displayed values. Where possible (e.g., triple systems), a fault should be identified and indicated in an instrument of the faulty system.

Color. General.

- Color shall have the same operational significance throughout the flight deck for all mechanical, electromechanical, and electronic equipment.
- Color coding shall be supported by a redundant means of coding (e.g., shape, position, function) for all operationally significant indications.
- Color shall be used with the aim of enhancing the distinction between indications, symbols and an-

nunciations, but the number of colors and extent of usage should be minimized to avoid loss of discrimination.

Color. Color Set.

- Color shall be selected from the following set of nine: Red, Tan/Brown, Amber, Yellow, Green, Cyan, Blue, Magenta, and White.

Society of Automotive Engineers (1997) ARP 5108
Abstract

This document sets forth design and operational recommendations concerning the human factors issues and criteria for airborne terrain separation assurance systems. The visual and aural characteristics are covered for both the alerting components and terrain depiction/situation components. The display system may contain any one of a combination of these components.

General Description

This ARP document includes sections on system functionality, design objectives, candidate graphic display options, and interface characteristics. The entries within the document are better described as general requirements than guidelines (e.g., The ability to sense flap and gear status should be provided). The sections on visual and aural alerts are more specific however.

Sample Guidelines

Flight Crew Interface Characteristics. Visual Alerts.

1) Two visual alerts should be provided for each pilot, one for warnings and one for cautions.
2) Visual alerts should be located within 15° of the pilot's centerline of vision.
3) The onset of the visual alert should occur simultaneously with the aural alert and no more than .5s after the system sensors detect the alerting situation.

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