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FEDERAL AVIATION ADMINISTRATION

STANDARD PRACTICE

ALARMS AND ALERTS IN THE TECHNICAL OPERATIONS ENVIRONMENT

Prepared by the Human Factors Research and Engineering Group

Distribution Statement: Approved for public release; distribution is unlimited.

Foreword

This standard has been generated for use by all organizations of the Federal Aviation Administration (FAA). This standard establishes FAA requirements to apply when a new or modified system or subsystem with an alarm and alert component is designed, developed, or acquired.

Currently, Technical Operations (TO) specialists use visual displays in centralized locations to monitor and control an increasing number of systems and facilities. As a result, these specialists become responsible for many different systems and facilities. Without standardization, these specialists are likely to encounter different symbolic representations (both visual and auditory) of the same object, and the use of the same or similar symbols to represent different objects. Increased standardization will reduce time and training requirements to learn, interpret, and respond to symbols. It will also reduce the risk of errors to interpret and respond to symbols.

There are many events that can cause a system to go into an alarm or alert *status*. Whether or not a condition triggers an alarm, or an alert, depends heavily on the particular system and the impact that the condition will have on the system and the National Airspace System (NAS) infrastructure as a whole. For example, it is possible for a system component to fail but not trigger an alarm or alert because the system is a minor component of the NAS infrastructure. Conversely, there are systems that a loss of redundancy will trigger an alarm because the systems are very important to the NAS infrastructure – thus it is critical for TO environments to have redundancy within these systems.

The TO specialists need to be informed of the administrative *states* of systems. These states include the general categories of available, reduced, unavailable, and failed. States are often indicated on monitor and control displays by location coding. Some systems are designed to have the status in the primary display area and the state in a secondary display area.

The TO specialists are exposed to systems that use *different* terms to describe a *similar* status or state. Additionally, TO specialists are exposed to systems that use *similar* terms to describe a *different* status or state. Therefore, TO specialists need a consistent coding scheme and presentation scheme that will allow the user to transfer knowledge gained from one system to the interpretation of status coding on another system. The coding scheme must effectively and consistently direct the user's attention to the priorities of the tasks.

Key to appropriate coding of status items is the need for action from each person using the system. The more urgent the need for action, the more perceptually prominent (attention-getting) the code needs to be. Therefore, the implementation of standardized symbols to represent common conditions, systems, facilities, and states would lead to improved human performance by alleviating the undesirable consequences.

In this standard, we build on the excellent work conducted by researchers at the Human Factors Research and Engineering Group (FAA, William J. Hughes Technical Center), and we summarize available knowledge regarding the presentation of alarm and alert signals in the TO environment. To aid the reader, we provide the reference source for each provision herein (see Appendix A).

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1. Introduction

1.1 Scope. This standard is intended to provide design criteria and guidance for the presentation of alarm and alert signals to the Technical Operations (TO) environment. It is recognized that some of the design criteria provided herein may be applicable to other environments and workforces. However, the reader is cautioned to evaluate these criteria prior to their application in other areas.

1.2 Applicability. This standard is intended to be applied when a new or modified system or subsystem, having an alarm and alert component, is being designed, developed, or acquired. This standard applies when a developmental system, a Commercial-Off-The-Shelf, or a non-developmental item solution is selected. Although this standard will be applied on a system-by-system basis, the requirements and design criteria also apply if the entire alarm and alert system within a facility is redesigned.

1.3 Technical Operations maintenance.

1.3.1 Technical Operations maintenance philosophy. The Technical Operations maintenance program is dedicated to ensuring safety and providing the best possible service at the lowest possible cost. The Federal Aviation Administration (FAA) is continually improving the National Airspace System (NAS) and services. Stringent risk management practices are incorporated into all maintenance actions prior to project implementation, configuration changes, or scheduled interruptions of the NAS to ensure that services are available and reliable.

1.3.2 Maintenance activities. TO maintenance activities are both periodic and corrective in nature. Periodic maintenance includes performance checks, preventative maintenance inspections, and routine maintenance. Corrective maintenance is maintenance performed to identify or correct a problem. It is typically performed to accomplish the restoration of service after an unscheduled interruption.

1.4 Alarm and alert system functions. The main functions of an alarm and alert system are definition, processing, prioritization, display, and control and management.

1.4.1 Definition. Alarm and alert definition is the specification of the types of process parameters to be monitored and displayed by the system and the setpoints to be used to represent those parameters. Important considerations are alarm and alert categories (the events and states from which alarms and alerts are selected), the criteria used to select alarm and alert parameters to represent the categories, the criteria for determining the setpoints, the verification process (the process by which alarm or alert inclusion are checked, and the process for assuring that non-alarms and alerts are not presented), and alarm and alert states (e.g., unacknowledged, acknowledged, cleared).

1.4.2 Processing. Alarm and alert processing refers to the alarms and alerts that are presented to the operators. Alarm and alert signal processing refers to the process by which signals from

sensors are evaluated to determine whether any of the monitored parameters have exceeded setpoints and to determine whether any of these deviations represent true alarm or alert conditions. Alarm and alert processing techniques help the operators (a) to cope with the volume of alarms and alerts, (b) to identify which alarms and alerts are significant, and (c) to reduce the need to infer system conditions.

1.4.3 Prioritization. Alarm and alert prioritization refers to the determination of the relative importance of all current alarm and alert conditions. This also includes consideration of alarm and alert message availability, that is, the process by which alarm and alert messages are selected for presentation to the operator based on the priority of their alarm or alert conditions. Common alarm and alert availability techniques are filtering (alarms or alerts determined to be less important, irrelevant, or otherwise unnecessary which are eliminated and are not available to the operators), suppression (alarms or alerts determined to be less important, irrelevant, or otherwise unnecessary which are not presented to the operators, but can be accessed upon request), and dynamic priority coding (alarms and alerts are separated into priority groups).

1.4.4 Display. The display aspects on alarms and alerts include both auditory and visual components. The auditory components are designed to capture the operator's attention to a change in the system, whereas the visual components guide attention to the appropriate alarm or alert and provide detailed information. To support the different functions of the alarm and alert system, multiple visual display formats may be required (e.g., a combination of separate displays and integrated displays). Thus, the display format of alarm and alert information and the degree to which that information is presented (separately or in an integrated fashion with other process information) are important considerations.

1.4.5 Control and management. The alarm and alert control and management aspects of the interface should be considered along two dimensions: (1) functional requirements (control functions needed by operators) and (2) implementation (how the functions are accomplished). In addition to the basic controls, newer alarm and alert systems provide many and varied management functions. For example, the operator may be able to define temporary alarms or alerts, adjust setpoints, control filtering options, and sort alarms or alerts according to many dimensions such as time, priority, and subsystem. These dynamic aspects of the interface should ensure that excessive workload demands are avoided, while the overall functional characteristics of the alarm and alert system are preserved. The dynamic aspects of the alarm and alert system should minimize disruption or confusion to operators, especially when the alarm and alert system changes modes of operation.

1.5 Hierarchy of signals

. The hierarchy of the signals presented to the TO personnel is described in this section.

1.5.1 Alarm. An alarm is a signal that indicates that the value of a monitored parameter, component, system, or function is outside the specified acceptable range. Immediate action is required to prevent loss of life, equipment damage, or disruption of National Airspace System (NAS) operations.

1.5.2 Alert. An alert is a signal that indicates the existence of a condition requiring immediate attention but not immediate action. An alert signal indicates that an operational status or a condition status of a NAS infrastructure resource has degraded or failed, or the resource functions may degrade or fail if action is not taken as soon as practicable.

1.5.3 Information. An informational signal indicates a safe or normal configuration, a condition of performance or operation of equipment, or it attracts attention and imparts information for routine action purposes.

1.6 Use of "shall" and "should."

As a standard, this document contains requirements and recommendations. Requirements are indicated by "**shall**" statements, whereas recommendations are indicated by "should" statements. A **shall** statement refers to a described, testable condition that must be met. A should statement represents *best practices* information that is applicable in most cases (but it may involve trade-offs, or it may be influenced by context-specific factors).

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2. Applicable Documents

2.1 General. The documents listed in this section are specified in sections 3 through 7 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. Every effort has been made to ensure the completeness of this list; however, users are cautioned that they must meet all specified requirements of documents cited in sections 3 through 7 of this standard, whether or not the document is listed.

2.2 Government documents. The following standard forms a part of this document to the extent specified herein. Unless otherwise specified, the issue of this document is cited in the solicitation or contract.

Ahlstrom, V., & Longo, K. (Eds.). (2003). ***Human Factors Design Standard*** *for the acquisition of commercial-off-the-shelf subsystems, non-developmental items, and developmental systems* (DOT/FAA/CT-03/05/**HF-STD-001**). Atlantic City International Airport, NJ: Federal Aviation Administration, William J. Hughes Technical Center.

2.3 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the reference cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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3. Definitions

3.1 Acknowledged. An alarm or alert is considered to be acknowledged when the operator has made some type of input (such as pressing a button) to indicate receipt of the alarm or alert message provided by the system. The act of acknowledging an alarm or alert typically causes the attention-getting characteristics to cease.

3.2 Alarm. An alarm indicates that the value of a monitored parameter, component, system, or function is outside the specified acceptable range.

3.3 Alarm and alert availability. Alarm and alert availability is the processing method by which the results of alarm and alert processing are made available to the operators. Three typical availability techniques are filtering, suppression, and prioritization.

3.4 Alarm and alert display. An alarm and alert display is the method(s) by which alarm and alert coding and messages are presented to the operators.

3.5 Alarm and alert message. An alarm and alert message is the information presented to the operator by the auditory, visual, and other display devices of the system in response to an alarm or alert condition.

3.6 Alarm and alert signal processing. Alarm and alert signal processing is the process by which signals from sensors are evaluated. This process, which includes signal validation and other techniques, determines whether an alarm or alert condition exists.

3.7 Alarm and alert system. An alarm and alert system is a system consisting of processing hardware, display hardware, and display software, which processes or analyzes signals from sensors and informs the operator (via visual and/or auditory displays) when monitored parameters deviate from specified limits (setpoints) or predefined conditions.

3.8 Alarm processing techniques. Alarm processing techniques are the rules or algorithms that are used to analyze sensor data to determine their importance, validity, and relevance, and to determine whether an alarm or alert message should be presented to the operator.

3.9 Alarm signal. An alarm signal is a signal that indicates the existence of a hazardous condition requiring immediate action to prevent loss of life, equipment damage, or disruption of the NAS.

3.10 Alert. An alert signal indicates an operational status or condition status of a NAS infrastructure resource in which the resource is still capable of performing its functions; however, some aspect of the resource has degraded or failed. Additionally, functions may degrade or fail if action is not taken as soon as practicable.

3.11 Alert signal. An alert signal is a signal that indicates the existence of a condition requiring immediate attention (but not immediate action).

3.12 Alphanumeric codes. Alphanumeric codes refer to the use of letters or numbers to represent information.

3.13 Audio signal. An audio signal is a signal that is heard rather than seen or felt.

3.14 Auditory icon. An auditory icon is a nonverbal, familiar everyday sound that intuitively conveys information about an object, for example, using a siren sound to represent an emergency vehicle.

3.15 Coding. Coding is a system of assigning meanings to symbols, letters, colors, or symbol characteristics to represent information. In general, coding is used to differentiate items of information; to attract a user's attention to important information; to attract a user's attention to unusual situations or potential problems; or to indicate changes in the state of a system. It can also be used to differentiate categories of data. When used effectively, coding can decrease visual search time – thus permitting the TO specialists to monitor and control systems of the NAS in a safer and more effective manner.

3.16 Contrast and contrast ratio. For this standard, contrast (C) is defined as C = [L(T)-L(B)]/L(B). For this contrast formula, L(T) is the total luminance of the image plus the background, and L(B) is the luminance of the background portion. Contrast ratio is defined as L(T)/L(B) and is one more than the contrast.

3.17 Core commands. Core commands are commands that are common across systems.

3.18 Decibel (dB). A decibel is a unit for expressing the ratio between two amounts of acoustic power, or for measuring the relative loudness of sounds. One decibel (0.1 bel) equals 10 times the common logarithm of the power ratio; that is, doubling the intensity of a sound means an increase of a little more than three decibel (3 dB).

3.19 Decibel (dBA). A dBA is a sound level in decibels, measured using A-weighting. The use of A-weighting causes the frequency response of the sound level meter to mimic that of the human ear (i.e., response is maximum at about 2,000 Hz, but less at very low or very high frequencies. A-weighted measurements correlate well with measures of speech interference and judgments of loudness).

3.20 Design eye position. The "design eye position" is the midpoint of the "design eye line" from which all workstation dimensions are related and referenced.

3.21 Earcon. An earcon is a simple, nonverbal sound arbitrarily assigned to represent an object; the auditory analogue of a visual or graphic icon.

3.22 Event. An event is any occurrence that may be significant. Specialists need to have specific types of events coded, such as alarms and alerts.

3.23 False Alarm or Alert. A false alarm or alert is the presentation of a signal indicating an out-of-tolerance condition when, in fact, an out-of-tolerance condition does not exist.

3.24 Filtering. Filtering is a processing technique by which irrelevant, less important, or otherwise unnecessary alarms and alerts are eliminated. These messages are not available to the specialists. This is in contrast to suppression, which does not make the messages immediately available but does allow the specialist to retrieve them.

3.25 Flag. A flag is a visual mechanical or electromechanical device used to show a change in the status of an indicator, instrument, or its associated system.

3.26 Highlighting. Highlighting is a means of directing the user's attention to a feature of the display. Highlighting methods include image reversal (reverse video), brightness contrast, color, underlining, blinking, flashing arrows, and changes in font.

3.27 Icon. An icon is a pictorial, pictographic, or other nonverbal representation of objects or actions.

3.28 Integrated display. An integrated display is a display that can operate in several modes or functions, one of which is the presentation of alarm and alert signals.

3.29 Master alarm signal. A master alarm signal is a visual signal that indicates that one or more alarm signals have been energized.

3.30 Master alert signal. A master alert signal is a visual signal that indicates that one or more alert signals have been energized.

3.31 Monitor alarm value. A monitor alarm value is an important parameter that it is monitored by a shutdown function, and has standard values with tolerances or limits around that value defined.

3.32 Normal. Normal indicates that a system is operating within its ideal operating range and no action is required.

3.33 Nuisance Alarm or Alert. A nuisance alarm or alert is the presentation of an alarm or alert signal that indicates a non-critical condition or situation; the condition or situation is not operationally relevant and does not require any action from the user. An example is an alarm that monitors temperature that activates when the temperature is on the threshold of changing. This alarm is continually activated because the temperature is controlled by a thermostat; no user action is required.

3.34 Pre-alarm value. A pre-alarm value is a parameter that has an alarm set to provide an indication that it is approaching an out-of-tolerance condition.

3.35 Prioritization. Prioritization is a processing technique that presents alarm and alert messages to the operator according to an evaluation of importance, often using categories of priority. The intent of this approach is to help the operators focus attention on the most important alarm and alert conditions when there are multiple alarms and alerts.

3.36 Setpoint. A setpoint is the value of a monitored parameter that defines the boundary between the parameter's normal range and an alarm or alert condition. An alarm or alert condition exists when the parameter exceeds the normal range that is defined by the upper and/or lower limit setpoints.

3.37 Signal validation. Signal validation is a processing technique by which signals from redundant or functionally related sensors are compared and analyzed to determine whether a true alarm or alert condition exists. The purpose is to prevent false alarms and alerts from being presented to the operator due to malfunctioning instrumentation, such as a failed sensor.

3.38 Soft alarm. See Pre-alarm value.

3.39 Sound localization. Sound localization is a listener's ability to identify the location or origin of a detected sound in distance and direction.

3.40 Speech interference level. Speech interference level is a measure of the effectiveness of noise in masking speech. It is the arithmetic mean of the same pressure levels of interfering noise (in dB) in the four octave bands centered on the frequencies 500, 1,000, 2,000, and 4,000 Hz, respectively. The unit of speech interference is the decibel (i.e., dB).

3.41 Suppression. Suppression is a processing technique by which alarms and alerts that are determined to be less important, irrelevant, or otherwise unnecessary are unavailable to the specialists, but can be accessed upon request. This is in contrast to filtering, which does not make the messages available.

3.42 Symbol coding. Symbol coding is the use of visual symbols or icons to represent status information to the user.

3.43 Tactile signal. A tactile signal is a signal that is felt rather than seen or heard.

3.44 Timbre. Timbre is the quality of a sound determined primarily by the fundamental frequency and harmonics it contains and, to a lesser extent, by its amplitude envelope.

3.45 Tone. A tone is a sound with definable regularity of oscillation or no oscillation (steady tone).

3.46 Unacknowledged. An unacknowledged alarm or alert is an alarm or alert that has not been acknowledged and displays attention-directing characteristics, such as rapid flashing.

3.47 Unmonitored/inactive. An unmonitored/inactive system is a system that is not monitored, directed, or controlled. This is a status imposed on the system by the user. A system may be unmonitored, unmanaged, or inactive because (a) it is awaiting a maintenance action; (b) it is not a system that is currently used; or (c) it is being used for training or similar reasons. Specialists may still need to see the status of individual components.

3.48 Visual angle. A visual angle is a measure (in degrees) of the size of the retinal image subtended by a viewed object. It represents the apparent size of an object based on the relationship between an object's distance from the viewer and its size (perpendicular to the viewer's line of sight). An object of constant size will subtend a smaller visual angle as it is moved farther from the viewer. Visual angle is typically defined in terms of minutes of visual arc.

3.49 Visual signal. A visual signal is a signal that is seen rather than heard or felt.

3.50 Voice message. A voice message is an audio signal with a verbal communication format.

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4. General Requirements

4.1 Functional requirements.

4.1.1 Meet human capabilities. The alarm and alert system **shall** be explicitly designed to take account of human capabilities and limitations, so that unacceptable demands are not placed on users by exceeding their perceptual and cognitive abilities (Ahlstrom & Longo, 2003).

4.1.2 System design. The design of an effective alarm and alert system

a. should not give audible and visible alarms or alerts when all systems are operating normally.

b. should reduce operator assimilation and memory demands.

c. should minimize the time required for the operator to detect and assess the situation, and to initiate corrective action(s).

d. should provide audible and/or visual signals that can be easily detected and understood.

e. should be standardized to maximize recognizability.

f. should allow for system growth capability that does not necessitate adding system components.

4.1.3 When to use. If equipment is not regularly monitored, an audio signal **shall** be provided to indicate malfunctions or conditions that would cause injury to personnel, an impact on the NAS operations, or equipment damage (Ahlstrom & Longo, 2003; Department of Defense [DOD], 1999).

4.1.4 Alarm and alert category. Conditions that fall into the alarm or alert category **shall** be based on the particular system or subsystem, the impact on the NAS, the likelihood of personal injury, the likelihood of equipment damage, and the operator's information requirements (DOD, 1997).

4.1.5 Provide greater probability of detection. An alarm and alert system or signal **shall** provide the user with a greater probability of detecting the triggering condition than his or her normal observation would provide in the absence of the system or signal (Ahlstrom & Longo, 2003; DOD, 1999).

4.1.6 Timely warning. Alarm and alert setpoints should be determined to ensure that the operator can monitor and respond to out-of-tolerance conditions in a timely manner (O'Hara, Brown, Lewis, & Persensky, 2002).

4.1.7 Prompt user action. Each alarm or alert should prompt user action. If no action is required, then that message should not be conveyed via an alarm or alert (ASTM International, 2007; O'Hara et al.).

4.1.8 Training for alarms and alerts. Training techniques should be devised to ensure that users are exposed to all forms of alarms and alerts as well as possible combinations of alarms and alerts, and that they understand how to deal with them (Ahlstrom & Longo, 2003).

4.1.9 Control and display integration.

4.1.9.1 Line of sight. Visual alarm and alert indications should be located within 60 degrees on either side of the line of sight of the operator's normal working position (O'Hara et al., 2002).

4.1.9.2 Access to controls and displays. Visual alarm and alert displays should be located near the controls and displays that are required for corrective or diagnostic action in response to the alarm or alert (O'Hara et al., 2002).

4.1.9.3 Interference from nearby lights. Indicator lights or other non-alarm or non-alert illuminated displays should be located away from alarm and alert displays, because they could be mistaken for an alarm or alert, or could mask an alarm or alert (O'Hara et al., 2002).

4.1.9.4 Distinct coding of controls. Alarm and alert system controls should be distinctively coded for easy recognition (O'Hara et al., 2002).

4.1.9.5 Consistent layout. Each set of alarm and alert subsystem controls should have the functions in the same relative locations (O'Hara et al., 2002).

4.1.9.6 Separate controls. Separate controls should be provided for silence, acknowledgment, and testing (O'Hara et al., 2002).

4.1.9.7 Disabling controls. Alarm and alert system control design **shall** not allow controls to be altered or disabled (O'Hara et al., 2002).

4.2 Selection and presentation of signals.

4.2.1 Modality. The alarm or alert signal **shall** be presented by the most effective modality (aural, visual, tactile) taking into consideration the user's tasks and the particular operating environment (Chapanis, 1996).

4.2.2 Selection of signals. The selection of signals, visual versus audio, **shall** be in accordance with Chapter 7 of the Human Factors Design Standard (Ahlstrom & Longo, 2003).

4.2.3 System characteristics. Alarm and alert systems should

a. inform the user that a problem exists.

b. inform the user of the priority and nature of the problem.

c. guide the user's initial responses.

d. confirm in a timely manner, whether or not the user's response corrected the problem (Ahlstrom & Longo, 2003).

4.2.4 Clear and unambiguous signals. Alarm and alert system signals **shall** be unambiguous, with a clear indication of the cause for the alarm or alert (Ahlstrom & Longo, 2003).

4.2.5 Indicate degree of problem. Alarm and alert signals should convey information as to the level of danger and indicate the degree of malfunction or emergency (Ahlstrom & Longo, 2003; Chapanis, 1996).

4.2.6 Easily recognizable. Alarms and alerts **shall** be immediately recognizable as such under all operating conditions, including normal, emergency, and degraded modes (Chapanis, 1996).

4.2.7 Multiple conditions. In the case of multiple, simultaneous conditions, alarms and alerts should be grouped and prioritized within their group by their urgency, with alarms presented first followed by alerts (Chapanis, 1996).

4.2.8 Transient or random signals. Alarm and/or alert signals **shall** not be actuated by transient, erroneous, or random sensor signals (DOD, 1997).

4.2.9 Luminance and contrast. At any location, the alarm and alert signals should have a luminance and contrast that is fully readable and easily recognizable in the full range of anticipated ambient lighting environments (DOD, 1997).

4.2.10 Glare and reflections. Visual alarm and alert signals should be presented and located to minimize glare and reflections caused by the ambient light (DOD, 1997).

4.2.11 Interference by ambient illumination. Auditory as well as visual alarms and alerts **shall** be provided in any area where the ambient illumination might interfere with the user's detection of the onset of the visual indication (Ahlstrom & Longo, 2003).

4.2.12 Alarm in appropriate mode. When a parameter value represents a fault in some modes and not in others, it should only be alarmed in the appropriate modes (Ahlstrom & Longo, 2003).

4.2.13 Allow access to current settings. When alarm and alert signals are based on user defined logic, the system should allow the users to access current settings that are specified in terms of the dimensions (variables) covered and values (categories) established as alarms and alerts (Ahlstrom & Longo, 2003).

4.2.14 Provide redundant visual signal. All nonverbal audio signals **shall** be accompanied by a visual signal that defines the condition (Ahlstrom & Longo, 2003; DOD, 1999).

4.2.15 Supplement visual displays. When used in conjunction with a visual display, an audio signal **shall** be supplementary or supportive, directing the user's attention to the appropriate visual display (Ahlstrom & Longo, 2003; DOD, 1999).

4.2.16 Provide help. When necessary, users **shall** be able to request help and related information for the operation and processing of alarms, alerts, messages, and signals (Ahlstrom & Longo, 2003).

4.3 Alarm and alert implementation.

4.3.1 Prioritize presentation. Alarms and alerts **shall** be automatically organized and presented to the users in prioritized form, with the most significant alarms receiving the highest priority. This prioritization can be based on the immediacy of a required action (Ahlstrom & Longo, 2003).

4.3.2 Present by significance. The presentation of alarms and alerts with higher operational significance should automatically override the presentation of alarms and alerts with lower operational significance (Ahlstrom & Longo, 2003; DOD, 1999).

4.3.3 Simultaneous signals. When two or more incidents or malfunctions occur simultaneously, the higher priority signal **shall** be presented first. After presentation of the highest priority signal, remaining signals **shall** be presented in descending order of priority (Ahlstrom & Longo, 2003; DOD, 1999).

4.3.4 Limit number of priority levels. The number of priority levels for alarm signals should be limited to four (Ahlstrom & Longo, 2003).

4.3.5 Make signals distinctive and consistent. Alarm and alert signals and messages **shall** be distinctive and consistent for each class of event (Ahlstrom & Longo, 2003).

4.3.6 Make information simple and understandable. Processed alarm and alert information should be simple enough that users can easily evaluate the meaning or validity of the resulting signals and messages (Ahlstrom & Longo, 2003).

4.3.7 Status indication. System status indication should be presented on a separate display from the alarm and alert indicators (Ahlstrom & Longo, 2003).

4.3.8 Filtering. Alarms and alerts that have no current operational significance should be filtered (Ahlstrom & Longo, 2003; ASTM International, 2007; O'Hara et al., 2002).

4.3.9 Suppressed alarms and alerts. When a single alarm or alert event invariably leads to subsequent alarm or alert events, the primary event should be shown with the subsequent events suppressed, as long as it does not interfere with the user's tasks (Ahlstrom & Longo, 2003; ASTM International, 2007; O'Hara et al., 2002).

4.3.10 Access to suppressed events. When an event is suppressed, users **shall** be able to access the information that is not shown (Ahlstrom & Longo, 2003; O'Hara et al., 2002).

4.3.11 Ease of accessing suppressed events. The method for accessing information on suppressed events should not be excessively complex (Ahlstrom & Longo, 2003).

4.3.12 Setpoints. The setpoints for initiating alarm and alert signals

a. **shall** not occur so frequently as to be considered a nuisance, and

b. **shall** provide personnel adequate time to monitor and take appropriate action in a timely manner; before it gets beyond the capability of the user to correct the problem (ASTM International, 2007; O'Hara et al., 2002).

4.4 Reliability.

4.4.1 Design for reliability. The alarm and alert system should be designed so that no single failure will result in the loss of a large number of alarms and alerts (O'Hara et al., 2002).

4.4.2 Component failures.

4.4.2.1 System failure. In the event of a complete system failure, the system **shall** integrate messages and report the system failure rather than the failure of components (Ahlstrom & Longo, 2003; DOD, 1999).

4.4.2.2 System or equipment failure. The system devices and circuits **shall** be designed to preclude alarm or alert signal failure in the event of system or equipment failure (Ahlstrom & Longo, 2003; DOD, 1999).

4.4.2.3 Display failure. Where alarms and alerts are presented on an electronic display or similar unit as the primary display, users should be able to access the alarms and alerts from more than one display (O'Hara et al., 2002).

4.4.2.4 Flasher failure. In the event of a flasher failure, the onset of an alarm or alert **shall** cause the light to illuminate and burn steadily, rather than not illuminate (ASTM International, 2007; O'Hara et al., 2002).

4.4.3 Circuit test. All system devices and circuits **shall** be equipped with test devices or other means of testing the operation of the alarm and alert system to include the visual and auditory signals (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1999; O'Hara et al., 2002).

4.4.4 Input validation. Alarm and alert system inputs (such as sensors) should be validated to ensure that spurious alarms or alerts are not presented to the user (Ahlstrom & Longo, 2003).

4.4.5 Noise filtering. Alarm and alert systems should have the capability to filter out noise signals that might present unnecessary alarms (Ahlstrom & Longo, 2003).

4.4.6 Loss of redundancy. When part of a redundant system, unit of equipment, module, or component becomes inoperable, an alarm or alert signaling the loss of redundancy **shall** be

provided to the user immediately (Ahlstrom & Longo, 2003; ASTM International, 2007; National Aeronautics and Space Administration [NASA], 1995).

4.5 False and nuisance alarms and alerts.

4.5.1 False alarms and alerts. False alarm and alert rates should be less than 2 percent (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

4.5.2 Nuisance alarms and alerts. The determination of alarm and alert setpoints should consider the trade-off between the timely alerting of an operator to an out-of-tolerance condition and the creation of nuisance alarms or alerts (O'Hara et al., 2002).

4.6 Design for maintainability.

4.6.1 Minimal interference. The alarm and alert system should be designed so that maintenance activities can be performed with minimal interference with the ongoing activities of the users (O'Hara et al., 2002).

4.6.2 Out-of-service systems. Taking a system or subsystem out of service to address an alarm or alert condition should require disabling the associated visual and audio signals (O'Hara et al., 2002).

4.6.3 Out-of-service indications. Cues for prompt recognition of an out-of-service alarm or alert should be designed into the system (O'Hara et al., 2002).

4.6.4 Extended illumination. If an alarm or alert indicator must be illuminated for an extended period because of maintenance activities, it should be distinctively coded for positive recognition during this period (O'Hara et al., 2002).

4.6.5 Maintenance aids. Aids should be provided, as needed, to assist personnel in performing alarm and alert system maintenance (O'Hara et al., 2002).

4.7 Maintenance record.

4.7.1 Non-volatile memory. A capability **shall** be provided to have all alarm and alert messages recorded in non-volatile memory (DOD, 1997).

4.7.2 Clearance. The memory **shall** be capable of being cleared by maintenance personnel when the existing record is no longer required (DOD, 1997).

4.8 Documentation.

4.8.1 Proper documentation. The alarm and alert system **shall** be properly documented, and clear roles and responsibilities established for maintaining and improving the system (Brown, O'Hara, & Higgins, 1999; O'Hara et al., 2002).

4.8.2 Process. There **shall** be a process established for handling access control and documentation of changes (properly documented and traceable) made to the alarm and alert system (Brown et al., 1999; O'Hara et al., 2002).

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5. Requirements for Visual Presentation of Alarms and Alerts

5.1 General.

5.1.1 Letters and numbers. Letters and numbers on electronic displays should be in conformance with the appropriate requirements of the Human Factors Design Standard related to the control-display technology being used (Ahlstrom & Longo, 2003).

5.1.2 Legends and abbreviations. Legends and abbreviations **shall** be in accordance with the Human Factors Design Standard, section 8.2.6 (Ahlstrom & Longo, 2003).

5.1.3 Display size.

5.1.3.1 Characteristics. Specific display design characteristics **shall** determine the minimum number of message lines to be displayed, allowing for the need to have characters large enough to be legible to users in their normal working positions (DOD, 1997).

5.1.3.2 Legends. Legends, including abbreviations, should be constructed so that any legend will fit on one line (DOD, 1997).

5.1.4 Character dimensions.

5.1.4.1 Dimensions and spacing. Character dimensions and spacing **shall** be selected for speed and accuracy of interpretation and **shall** be in accordance with the Human Factors Design Standard, section 6.1.2 (Ahlstrom & Longo, 2003).

5.1.4.2 Height. The height of symbols and characters **shall** subtend a viewing angle of no less than 20 minutes of arc when measured from the design eye position (Ahlstrom & Longo, 2003; DOD, 1997).

5.1.4.3 Prior evaluation. Character dimensions and fonts **shall** be evaluated and approved by the acquiring activity before implementation.

5.1.5 Display luminance and contrast.

5.1.5.1 Readability. Display luminance and contrast **shall** be such that alarm and alert messages are easily readable from the design eye position in any operational ambient lighting condition (DOD, 1997).

5.1.5.2 Discriminability. Luminance and contrast of color displays **shall** ensure the discriminability of the alarm and alert message from the background (DOD, 1997).

5.1.5.3 Contrast detection. There **shall** be sufficient contrast between flashing and fully illuminated alarms and alerts, and between illuminated and non-illuminated alarms and alerts, so

personnel can reliably discriminate each state (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1997).

5.1.5.4 Minimum display luminance. The minimum display luminance **shall** not be less than 1.5 foot-Lamberts (fL) (DOD, 1997).

5.1.5.5 Luminance for electronic display presentation. For electronic display presentations, either the symbol or its background, whichever luminance is higher, should be 10 fL or more (Duncanson, 1994).

5.1.5.6 Luminance contrast. The ratio of luminance between the symbol and the surrounding background should be at least 3:1, with 7:1 preferred (DOD, 1997; Duncanson, 1994).

5.1.5.7 Dimming. The display **shall** not be allowed to be dimmed to such a level that would make the alarm or alert message unreadable (DOD, 1997).

5.1.6 Control and display integration. The requirements for control and display integration **shall** be as specified in the Human Factors Design Standard appropriate to the control-display technology being used (Ahlstrom & Longo, 2003).

5.2 Number and location of displays.

5.2.1 Presentation of messages. Unless otherwise specified, all alarm and alert messages **shall** be presented within the operator's 30 degree (total included angle) forward cone of vision, on a single display surface (DOD, 1997).

5.2.2 Multiple displays. If more than one display is present, the display monitor or panel farthest to the left should present the alarm and alert messages (DOD, 1997).

5.2.3 Interactive functions. If interactive control functions are included with the display, they **shall** be within the anthropometric reach of the operator using them (DOD, 1997).

5.2.4 Repetitive grouping. Repetitively appearing groups of alarms and alerts **shall** have the same arrangement and relative location on different panels and consoles. All alarm and alert controls that appear in more than one location **shall** be consistently placed on panels and consoles (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1999).

5.3 Message presentation.

5.3.1 Alarm message precedence. The presentation of alarm messages **shall** have precedence over alert messages and routine display information (DOD, 1997).

5.3.2 Alert message precedence. The presentation of alert messages **shall** have precedence over routine display information (DOD, 1997).

5.3.3 Message location. Whenever one or more alarm or alert conditions are present, the message(s) **shall** appear in a location dedicated for the presentation of alarm and alert messages (DOD, 1997).

5.3.4 Blank out display symbology. The alarm or alert message location may blank out any display symbology or video when presenting a message (DOD, 1997).

5.3.5 Size of message area. Only the appropriate active alarm or alert message(s) **shall** appear; however, the location for presenting the alarm and alert messages **shall** be large enough to present at least as many messages as there are alarms within the system (DOD, 1997).

5.3.6 Message acknowledgment. After the operator has acknowledged an alarm or alert, the system should change to a visually distinct acknowledged state (O'Hara et al., 2002).

5.3.7 Message format.

5.3.7.1 Convey nature of problem. Alarm and alert messages **shall** concisely convey the nature of the problem and the specific subsystem or location (DOD, 1997).

5.3.7.2 Standard syntax. A standard syntax is desirable for all messages, but **shall** be subordinate to a clear statement of the problem (DOD, 1997).

5.3.7.3 Grouping. Messages should be grouped by urgency level, with the highest priority messages listed first (DOD, 1997; O'Hara et al., 2002).

5.3.7.4 Grouping options. In addition to priority grouping, users should have the capability to group messages according to operationally relevant categories such as function, chronological order, and status (O'Hara et al., 2002).

5.3.8 Overflow memory.

5.3.8.1 Display messages. A system to display messages stored in overflow memory **shall** be used when the number of active messages exceeds the capacity of the display (DOD, 1997).

5.3.8.2 Operator action. Alarm and alert messages **shall** remain presented until either the causative condition has been corrected or the operator takes an action to store the message in overflow memory for later recall (DOD, 1997).

5.3.8.3 Alert operator of more messages. If there are more messages than there is space to display them all, an indication **shall** be provided to the operator that additional alerts exist (DOD, 1997).

5.3.8.4 Storage and recall. Overflow messages **shall** be stored, and a capability **shall** be provided to recall/scroll through stored alarms and alerts (DOD, 1997).

5.3.8.5 New messages.

a. If a new alarm or alert condition arises, the new message **shall** be placed with messages of equal criticality.
b. If space is limited on the display, a message of lower criticality **shall** be replaced.
c. The replaced message **shall** be moved into overflow.
d. If no lower criticality message exists, a message of equal criticality **shall** be moved into overflow.
e. Messages placed in overflow **shall** be grouped with messages of equal criticality (DOD, 1997).

5.3.9 Minimum message duration. It is possible for an alarm or alert condition to exist for such a short period that an operator may not have a chance to identify the condition, even though the condition has been cured or ended. Therefore, a minimum message display time of 3 seconds is suggested for all alarm and alert messages (DOD, 1997).

5.3.10 Setpoint values. If an alarm or alert condition requires verification before action is taken, the relevant setpoint limits should be included in the alarm or alert message when the information on an electronic display or similar display (O'Hara et al., 2002).

5.3.11 Parameter values. Out-of-tolerance parameter values should be highlighted in the alarm or alert message when the alarm or alert information is presented on an electronic display or similar display (O'Hara et al., 2002).

5.4 Coding.

5.4.1 General.

5.4.1.1 Coding effectiveness. The coding scheme(s) used in the alarm and alert system should ensure rapid detection and interpretation by users under all expected operating conditions (O'Hara et al., 2002).

5.4.1.2 Coding complexity. The number of different coding techniques should be kept to a minimum, so that the coding system does not become too difficult to use or understand (O'Hara et al., 2002).

5.4.1.3 Primary coding mechanism. Based on its strong attention getting qualities, color **shall** be used as a primary coding mechanism to convey alarm and alert status (Ahlstrom & Muldoon, 2004).

5.4.1.4 Judicious use. Coding techniques that have strong attention-getting qualities (for example, color and flashing) should be used judiciously (Ahlstrom & Muldoon, 2004).

5.4.1.5 Consistency. The coding conventions that are used should be applied consistently within a system and across related systems (Ahlstrom & Muldoon, 2004).

5.4.1.6 Special codes. Although special codes should be avoided where possible, it may be the case that the user's needs that relate to a system require a special code. If a code is assigned a special meaning in a display, the meaning should be defined at the bottom of the display (Ahlstrom & Muldoon, 2004).

5.4.1.7 Codes mapped to different systems. Individual users should not be able to change the status codes that are mapped to different system states and conditions (Ahlstrom & Muldoon, 2004).

5.4.1.8 Functional rather than arbitrary. When codes are used, they should be functional and meaningful (rather than decorative and arbitrary) (Ahlstrom & Muldoon, 2004).

5.4.1.9 Redundant codes. Redundant codes should be used for alarms and alerts that require rapid action (O'Hara et al., 2002).

5.4.2 Color coding.

5.4.2.1 Convey information to user. In general, color should be used to augment a user's understanding of the information being presented, to attach specific meaning to a portion of text or a symbol, to direct a user's attention to something (highlighting critical elements), to reduce clutter, to identify and classify information, to indicate changes in status (as a formatting aid), and to enhance legibility (Ahlstrom & Muldoon, 2004).

5.4.2.2 Consistency. Colors **shall** be used consistently within a screen, within a system, and across related systems (Ahlstrom & Muldoon, 2004).

5.4.2.3 Number of colors.

5.4.2.3.1 Use conservatively. Color should be used conservatively. Color should be used only if it facilitates user understanding or performance (Ahlstrom & Muldoon, 2004).

5.4.2.3.2 Total number of colors. The total number of colors used for coding should not exceed four for a single alphanumeric screen and seven for a set of related screens (Ahlstrom & Muldoon, 2004).

5.4.2.4 Meanings assigned to colors.

5.4.2.4.1 Established meanings. Well established meanings should be retained, limiting one meaning per color (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2004; DOD, 1999).

5.4.2.4.2 Red. Red (RGB – 255,60,60; CIE x = .61-.62 and y = .33-.35) **shall** be used to indicate conditions such as no-go, error, failure, alarm, or malfunction (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.3 Flashing red. Flashing red **shall** only be used to indicate an emergency condition requiring immediate action (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.4 Yellow. Yellow (RGB – 255,255,0; CIE x = .41-.42 and y = .50-.51) or amber **shall** be used to indicate marginal conditions, caution, or alert (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.5 Green. Green (RGB – 0,255,0; CIE x = .29-.32 and y = .55-.60) should be used to indicate that it is OK to proceed, normal, satisfactory, or within tolerance status (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.6 White. White (RGB – 225,225,225; CIE x = .31-.36 and y = .33-.37) **shall** indicate alternative functions or system conditions that do not have operability or safety implications (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.7 Blue. Blue (RGB – 30,80,200; CIE x = .16-.18 and y = .11-.18) should be used only for advisory or informational items (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.8 Gray. Items that are unmonitored, unmanaged, inactive, out of service for a long term, or intentionally taken off-line, should be coded as gray at the topmost level to indicate that the user can ignore these items (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2004; DOD, 1999).

5.4.2.4.9 Color key. If the use of color does not follow well-established meanings, or if a color is used for which there is no conventional association, a color key **shall** be readily accessible for the user (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.2.4.10 Colors to avoid. Highly saturated colors from different parts of the visual spectrum should be avoided (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2004; DOD, 1999).

5.4.2.4.11 Color combinations to avoid. The color combinations in Table I **shall** be avoided (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2004; DOD, 1999).

TABLE I. **Color combinations to avoid**

Yellow text on a white background	Magenta text on a black background
Yellow text on a green background	Magenta text on a green background
Yellow text on a purple background	Saturated yellow and green
Red text on a black background	Saturated red and green
Blue text on a black background	Saturated blue and green
Green text on a white background	Saturated red and blue

5.4.2.5 Size of color-coded symbols. A symbol that is color-coded **shall** subtend a visual angle of at least 20 minutes (Duncanson, 1994).

5.4.2.6 Luminance of color-coded symbols. Color-coded symbols **shall** have a minimum luminance of 1 fL (Duncanson, 1994).

5.4.2.7 Refresh rate of color-coded symbols. Color-coded symbols **shall** have a refresh rate that provides no perceptible flicker (Duncanson, 1994).

5.4.3 Flash (Blink) Coding.

5.4.3.1 Urgent need for user attention. Flash coding should only be used to indicate a situation with an urgent need for user attention (Ahlstrom & Muldoon, 2004).

5.4.3.2 Flash rate. The flash rate **shall** be between 3 and 5 Hz with an on/off cycle of approximately 50 percent (Ahlstrom & Longo, 2003; DOD, 1999).

5.4.3.3 Number of flash rates. No more than two flash rates **shall** be used (Ahlstrom & Longo, 2003; DOD, 1999).

5.4.3.4 Multiple flash rates. If multiple flash rates are used to indicate alarms and alerts, a faster flash rate should indicate greater urgency than a slower flash rate (Ahlstrom & Muldoon, 2004).

5.4.3.5 Second flash rate. Where two flash rates are used, the second rate **shall** be 1-2 Hz (Ahlstrom & Longo, 2003; DOD, 1999).

5.4.3.6 Simultaneous presentations. Flashing presentations that could be simultaneously active should have synchronized flashes (Ahlstrom & Longo, 2003; DOD, 1999).

5.4.3.7 Flashing text. If flash coding is used on text, the flash rate should be 0.3 to 1 Hz with an on/off cycle of 70 percent (Ahlstrom & Longo, 2003; Ahlstrom & Muldoon, 2002, 2004; DOD, 1999).

5.4.3.8 Flash rates to avoid. Flashing **shall** avoid rates of 10 to 25 Hz to minimize the risk of seizures for those with photosensitive epilepsy (Ahlstrom & Muldoon, 2004).

5.4.4 Alphanumeric coding.

5.4.4.1 Meaningful rather than arbitrary. Alphanumeric codes should be meaningful rather than arbitrary (Ahlstrom & Muldoon, 2004).

5.4.4.2 Not sole means. Alphanumeric coding should not be the sole means of drawing attention to an alarm or alert (Ahlstrom & Muldoon, 2004).

5.4.4.3 Consistency. Alphanumeric codes should use either uppercase or lowercase letters; use consistently (Ahlstrom & Muldoon, 2004).

5.4.4.4 Lowercase letters. If lowercase letters are used, the character height of text, depending on viewing distance, should be between 20 and 22 minutes of arc, with a minimum of 16 minutes of arc (Ahlstrom & Muldoon, 2004).

5.4.4.5 Letters and numbers. If the coding includes letters and numbers, the letters should be grouped together and the numbers should be grouped together rather than interspersing letters and numbers (Ahlstrom & Muldoon, 2004).

5.4.4.6 Labels. If letters and numbers are used in a label, the letters and numbers **shall** be easily distinguishable; that is, avoid easily confusable letters and numbers such as "Z" and "2" or "O" and "0" (Ahlstrom & Muldoon, 2004).

5.4.4.7 Punctuation. Punctuation should be avoided in alphanumeric codes (Ahlstrom & Muldoon, 2004).

5.4.4.8 Recall of codes. Arbitrary codes or codes that are to be recalled by the users **shall** be avoided (Ahlstrom & Muldoon, 2004).

5.4.4.9 Numeric codes. Purely numeric codes should be avoided (Ahlstrom & Muldoon, 2004).

5.4.5 Brightness coding.

5.4.5.1 Number of levels. When brightness coding is used, the number of brightness levels should not exceed three, with two levels as optimal (Ahlstrom & Muldoon, 2004).

5.4.5.2 Brighter level more critical. The brighter of the two levels should be used to code the more critical item, with the luminance levels differing by a ratio of 2:1 (Ahlstrom & Muldoon, 2004).

5.4.5.3 Consistency. Brightness coding should have a consistent meaning within a system and across related systems (Ahlstrom & Muldoon, 2004).

5.4.6 Highlighting.

5.4.6.1 Highlighting with dark backgrounds. When highlighting is used on dark backgrounds, the highlighting should be white with dark text (Ahlstrom & Muldoon, 2004).

5.4.6.2 Highlighting with light backgrounds. When highlighting is used on light backgrounds, the highlighting should be dark with white text (Ahlstrom & Muldoon, 2004).

5.4.6.3 Reverse video. If reverse video (brightness inversion) is used to draw the user's attention to an alarm or alert, it should return to normal after the user has responded, or when the alarm or alert no longer exists (Ahlstrom & Muldoon, 2004).

5.4.7 Shape coding.

5.4.7.1 Discernable from one another. Shapes used for alarms and alerts should be clearly discernable from one another, avoiding similar geometric forms (Ahlstrom & Muldoon, 2002, 2004).

5.4.7.2 Identifiable without reference. Where geometric shape coding is used and each shape is required to be identified without reference to any other, the number of shapes in the entire set, including alarms and alerts, should not exceed five (Ahlstrom & Muldoon, 2002, 2004).

5.4.7.3 Screen resolution. The screen resolution should be adequate to allow the user to differentiate shapes under operational conditions (Ahlstrom & Muldoon, 2004).

5.4.8 Size coding.

5.4.8.1 Presented in largest size. When used, alarms and alerts **shall** be presented in the largest size (Ahlstrom & Muldoon, 2004).

5.4.8.2 Relationship to smaller size. The largest size should be 1.5 times the height of the next smaller size (Ahlstrom & Muldoon, 2004).

5.4.9 Location (spatial) coding.

5.4.9.1 Assigned prominent position. Alarms and alerts **shall** be assigned the most prominent position within a display; typically either the center of the screen or the top left (Ahlstrom & Muldoon, 2004).

5.4.9.2 Same general location. Alarms and alerts **shall** occupy the same general location within a system and across related systems (Ahlstrom & Muldoon, 2004).

5.4.10 Symbol coding. Symbol coding, though uncommon, may be used in alarm and alert status displays to indicate whether or not an item has been acknowledged (Ahlstrom & Muldoon, 2004).

5.5 Mechanical visual signals.

5.5.1 Use. When mechanical visual signals are used, the signal **shall** be in accordance with the Human Factors Design Standard for a given type of signal device (Ahlstrom & Longo, 2003).

5.5.2 Color. Mechanical visual signals should have white markings on a black background or as specified by the acquiring activity (DOD, 1997).

5.5.3 Markings. Mechanical visual signals **shall** be marked with a legend or symbol that is descriptive of the information being given (DOD, 1997).

5.5.4 Luminance of flags. The markings on flags **shall** be as luminous as the markings on the indicator or display in which it is mounted (DOD, 1997).

5.5.5 Luminance of indicators. Indicator luminance for lighted displays **shall** be in accordance with the Human Factors Design Standard (Ahlstrom & Longo, 2003).

5.6 Core commands

. Core commands, if used, **shall** use consistent terminology across systems so that different commands are not used to accomplish the same functions, or the same or similar commands are not used to accomplish different functions (Ahlstrom & Muldoon, 2003).

6. Requirements for Audio Presentation of Alarms and Alerts

6.1 General. Audio signals should be provided (as necessary) to warn personnel of impending danger, to alert a user to a critical change in system or equipment status, to alert the user to the existence of a new alarm or alert, to remind a user of critical actions that must be taken, or any other condition of which the user must be made immediately aware (Ahlstrom & Longo, 2003; O'Hara et al., 2002).

6.1.1 Use of auditory signals. Auditory signals **shall** be used only when such signals contribute to understanding of and appropriate responses to the operational and task environment (Ahlstrom & Longo, 2003).

6.1.2 Avoid negative consequences. Auditory signals **shall** not result in user or operator confusion, errors, or inefficiencies in response to the signal (Ahlstrom & Longo, 2003).

6.1.3 Advantages to audio signals. An audio signal should be provided when any of the following conditions apply.

a. The information to be processed is short, simple, transitory, and requires an immediate or time-based response.
b. The use of a visual display might be inappropriate because of overburdening of the visual modality, ambient light variability or limitation, user mobility, degradation of vision by vibration, other environmental considerations, or anticipated user inattention.
c. The criticality of a response to a visual signal makes supplementary or redundant alerting desirable.
d. It is desirable to warn, alert, or cue the user for subsequent or additional responses.
e. Practice has created anticipation of an audio display.
f. Voice communication is necessary or desirable (Ahlstrom & Longo, 2003; DOD, 1999).

6.1.4 Compatible with environment. The intensity, duration, and source location of audio alarms and signals **shall** be compatible with the acoustical environment of the intended receiver (Ahlstrom & Longo, 2003; DOD, 1999).

6.1.5 Signal levels. Each audible alarm and alert signal **shall** be detectable in all locations where personnel may be when their response to the condition is required (Ahlstrom & Longo, 2003; ASTM International, 2007; O'Hara et al., 2002).

6.1.6 Signals for normal conditions. Auditory alarm and alert signals should not be used to indicate normal conditions (Ahlstrom & Longo, 2003).

6.1.7 Signal type. When an audio signal is used, the particular type of signal (tone, complex sound, or speech) should be the best for the intended use. Appendix C provides guidance on signals that are currently found in the TO environment; Appendix E provides considerations for the audio presentation of alarm and alert signals (DOD, 1999).

6.1.7.1 Alarm – active channel. The alarm signal should be a complex tone that sounds four times in succession followed by approximately 4 seconds of silence; repeats until acknowledged. This provision also applies to the primary (active) channel of a system that has a primary and backup (non-active) channel (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.7.2 Alarm – backup channel. The alarm signal for a backup (non-active channel) should be a double-beep complex tone that sounds three times in succession followed by approximately 4 seconds of silence; repeats until acknowledged (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.7.3 Alarm – testing or training channel. The alarm signal for use during testing and/or training should be a "sonar ping" complex tone that sounds three times in succession followed by approximately 4 seconds of silence; repeats until acknowledged (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.7.4 Alert – active channel. The alert signal should be a complex tone that sounds once followed by approximately 3 seconds of silence; repeats until acknowledged. This provision also applies to the primary (active) channel of a system that has a primary and backup (non-active) channel (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.7.5 Alert – backup channel. The alert signal should be a double-beep complex tone that sounds once followed by approximately 3 seconds of silence; repeats until acknowledged (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.7.6 Alert – testing or training channel. The alert signal for use during testing and/or training should be a "sonar ping" complex tone that sounds once followed by approximately 3 seconds of silence; repeats until acknowledged (Technical Operations Human Factors Standardization Team, personal communication, January 24, 2008).

6.1.8 User evaluation. Auditory signals **shall** be tested and evaluated for usability, operational suitability, and user acceptance using representative users in as near to a realistic operational environment as possible before the signals are incorporated into a system (Ahlstrom & Longo, 2003).

6.1.9 User setting of parameters. When appropriate to the task, a system or application should allow a user to set the parameter or condition that results in a software-generated alarm, alert, or status message (Ahlstrom & Longo, 2003).

6.1.10 When users should not set parameters. User setting of parameters should not be allowed when the settings by one user might affect the reception of alarms and alerts by another user; when the settings might affect the safety of systems, equipment, or personnel; or when the alarm and alert parameters are determined by functional, procedural, or legal requirements (Ahlstrom & Longo, 2003).

6.1.11 Alerting capabilities. Signals with high alerting capacities should be provided when the system or equipment imposes a requirement on the user for concentration of attention (Ahlstrom & Longo, 2003; DOD, 1999).

6.1.12 Avoid startling. Signals should not be so startling that they preclude appropriate responses or interfere with other functions by diverting attention away from other critical signals (Ahlstrom & Longo, 2003; DOD, 1999).

6.1.13 Auditory feedback. The most common auditory feedback, the system beep, should be used with other forms of notification such as flashing or message dialogs (Ahlstrom & Longo, 2003).

6.2 Audio alarm and alert signals.

6.2.1 Number of signals.

6.2.1.1 Number of audio signals for absolute identification. When absolute identification is required, the number of signals to be identified should not exceed four (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.1.2 Single audio signal. A single audio signal should be used in conjunction with multiple visual displays only if immediate identification of the appropriate visual display is not critical to the safety of personnel or system performance (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.2 Differentiating signals.

6.2.2.1 Distinguishing signals. Auditory signals that require different user responses should be easily distinguishable from one another (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1999).

6.2.2.2 Alarm versus alert signals. Audible signals to denote an alarm condition **shall** be noticeably different from audible signals identifying an alert condition (Ahlstrom & Longo, 2003).

6.2.2.3 Differentiation from routine signals. Audio alarms and alerts intended to attract the user's attention to a malfunction or failure **shall** be different from routine signals such as bells, buzzers, random noises generated by air conditioning and other equipment, and normal operation noises (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.2.4 Multiple audio signals. When several different audio signals will be used to alert a user to different conditions, the signals **shall** be distinctive in intensity, pitch, or use of beats and harmonics (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.2.5 Unsuitable auditory signals. Auditory signals should not be used if they resemble sounds that can occur in the actual operational setting, such as sounds that are similar to navigational signals or radio transmissions, or hisses or humming sounds similar to electrical interference (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.2.6 Non-interference. Audio alarm and alert signals **shall** not interfere with any other critical functions or signals, mask other critical audio signals, or conflict with other auditory signals (Ahlstrom & Longo, 2003; DOD, 1999; O'Hara et al., 2002).

6.2.3 Signal meaning.

6.2.3.1 Consistent meanings. The meaning of audio alarm and alert signals selected for a particular function in a system should be consistent with signal meanings already established for that function (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.3.2 Established signals. Established signals should be used provided they are compatible with the acoustic environment and voice communication systems (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.3.3 New meanings for established signals. Established signals **shall** not be used to convey new meanings (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.4 Nature of signals.

6.2.4.1 Intermittence. Auditory signals should be intermittent rather than continuous (Ahlstrom & Longo, 2003).

6.2.4.2 Construction. Auditory signals should be constructed from complex sounds, for example, timbres rather than from pure tones (Duncanson, 1994).

6.2.4.3 Two-element signals. Audio warning signals should consist of two elements, an attention-getting signal and an identifying or action signal (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.4.4 Modulated signals. Modulated alarm and alert signals should provide either beeping sounds (from 1 to 8 beeps per second) or warbling sounds (that rise and fall in pitch from 1-3 Hz) (Ahlstrom & Longo, 2003).

6.2.5 Duration.

6.2.5.1 Two-element signals. When reaction time is critical and a two-element signal is used, an attention-getting signal of 0.5 seconds duration **shall** be provided followed by an identifying or action signal, with all essential information being transmitted in the first 2 seconds of the identifying or action signal (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.5.2 Single-element signal. If a single-element signal is used, all essential information **shall** be transmitted in the first 0.5 seconds (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.5.3 Duration. Audio alarm and alert signal duration **shall** be at least 0.5 seconds and may continue until the appropriate response is made (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.5.4 Signal termination. Completion of a corrective action by the user or by other means **shall** automatically terminate the signal (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.6 Frequency.

6.2.6.1 Frequency range. The frequency range of an alarm or alert signal **shall** be between 200 and 5,000 Hz, preferably between 500 and 3,000 Hz (Ahlstrom & Longo, 2003; DOD, 1999; O'Hara et al., 2002).

6.2.6.2 Frequency for long distances. When a signal must be audible at a distance of 300 m (985 ft) or more, the frequency **shall** be below 1,000 Hz (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.6.3 Signals around obstacles. When the signal must be heard around obstacles or through partitions, the frequency **shall** be below 500 Hz (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.6.4 Frequencies differing from background. The selected frequency band **shall** differ from the most intense background frequencies (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.6.5 Spurious signals. The frequency of an alarm or alert tone **shall** be different from that of the electric power employed in the system to preclude the possibility that a minor equipment failure might generate a spurious signal (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.6.6 Frequencies difficult to localize. Mid-frequencies (1,500-3,000 Hz) should not be used for auditory alarms and alerts that require localization (Ahlstrom & Longo, 2003).

6.2.7 Intensity (loudness).

6.2.7.1 Audibility. An alarm or alert signal **shall** provide an audio level (at least one octave band between 200 and 5,000 Hz) so that the sound pressure level (SPL) of the signal is at least 10 dB(A) above the ambient noise level, or 20 dB(A) above the amplitude of the masked threshold (or at such a level that assures personnel are adequately alerted to the danger or status) when measured within a foot (1 foot) of the responder's ear or at more than 2 feet from the signal (Ahlstrom & Longo, 2003; DOD, 1999; NASA, 1995).

6.2.7.2 Environmental compatibility. The intensity, duration, and source location of an auditory signal should be compatible with the acoustic environment of the intended receiver as well as with the requirements of other personnel within acoustic range of the signal (Ahlstrom & Longo, 2003).

6.2.7.3 Exceeding ambient noise. Auditory signals **shall** exceed the prevailing ambient noise level by at least 10 dB(A), without exceeding 115 dB(A) for emergency signals or 90 dB(A) for other signals (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.7.4 Maximum intensity. The intensity of evacuation and emergency signals **shall** not exceed 115 dB(A). The intensity of other signals **shall** not exceed 90 dB(A) (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.7.5 Compatibility with clothing and equipment. When the audio signals must be heard and understood through equipment or garments (e.g., parka hoods and hearing protective devices covering the ears of a listener), audio signals **shall** be loud enough to compensate for the attenuation characteristics of the garments, without exceeding 115 dB(A) for emergency signals and 90 dB(A) for other signals (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.7.6 Control of volume. The user, the sensing mechanism, or both **shall** control the volume (loudness) of an audio signal depending on the operational situation and the safety of personnel (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.7.7 Volume limits. Volume control movement **shall** be restricted to prevent reducing the volume to an inaudible level or increasing it to an unacceptably high level (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.7.8 Intensity coding. Auditory signals should not be coded by intensity (O'Hara et al., 2002).

6.2.8 Acknowledging signals.

6.2.8.1 Acknowledging and terminating alarms and alerts. A system or application **shall** provide users with a means of acknowledging alarms and alerts as well as a means of turning off alarm and alert signals once they have been acknowledged or the condition generating the signal has been corrected (Ahlstrom & Longo, 2003).

6.2.8.2 Special acknowledgment. When a user must acknowledge a special or critical alarm or alert in a unique way (e.g., with a special combination of key strokes), this special acknowledgment **shall** not inhibit or slow the response to the condition initiating the alarm or alert (Ahlstrom & Longo, 2003).

6.2.8.3 Alarm or alert reset. A system or application **shall** provide users with a simple means for turning off non-critical auditory alarms or alerts without erasing any displayed message that accompanies the auditory signal (Ahlstrom & Longo, 2003).

6.2.8.4 Procedures for acknowledging alarms and alerts. Procedures for acknowledgment and termination of alarms and alerts **shall** not decrease the speed and accuracy of operator reaction to the alerting situation (Ahlstrom & Longo, 2003).

6.2.8.5 Consistent means of acknowledging. A simple, consistent means of acknowledging auditory signals **shall** be provided (Ahlstrom & Longo, 2003).

6.2.8.6 Acknowledging loss of redundancy. Users **shall** be able to acknowledge an alarm signaling the loss of redundancy, with the lack of available redundancy continuously displayed, until the redundant system, equipment, module, or component becomes operable again (Ahlstrom & Longo, 2003; NASA, 1995).

6.2.8.7 Automatic reset. An automatic reset function for audio signals **shall** be provided, whether the signals are designed to terminate automatically, manually, or both. The automatic reset function **shall** recycle the signal system such that the system can sound again if the condition reappears (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.8.8 Banding to mode switches. Volume controls may be banded to mode switches to provide maximum output during operational phases in which intense noise can occur and to provide reduced volume at other times. This banding **shall** not be done if there is a possibility that intense noise could occur in an emergency situation during a phase in which the volume would be decreased below an audible level (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.9 Presentation over headsets.

6.2.9.1 Headset. When a person wears earphones that cover both ears during normal equipment operation, the audio signal **shall** be directed to the headset as well as to the work area (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1999).

6.2.9.2 When not to use headsets. Binaural headsets should not be used in any operational environment with ambient noise below 85 dB(A) if the environment contains sounds that provide useful information but that information cannot be directed to the person's headset (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.9.3 Separate channels. When feasible, an alarm or alert signal delivered to a headset that might mask another essential audio signal should be delivered to one ear and the other signal to the other ear (Ahlstrom & Longo, 2003; DOD, 1999).

6.2.9.4 Dichotic presentation. When earphones will be worn in an operational environment, a dichotic presentation should be used whenever feasible, with the signal alternating from one ear to the other by means of a dual-channel headset (Ahlstrom & Longo, 2003; DOD, 1999).

6.3 Voice (verbal) alarm and alert signals.

6.3.1 General. Caution should be applied when deciding on the use of verbal alarm and alert signals; see Appendix E for additional guidance.

6.3.1.1 When to use. Voice signals should be

a. used to supplement visual displays when communication flexibility is necessary.
b. used when coded signal meanings are numerous or may be forgotten.
c. used for presentation of complex directions or instructions.
d. used when ambient noise may mask simple tonal signals.
e. used in conjunction with tonal signals.
f. used for presentation of continuous information when the rate of change is low (Ahlstrom & Longo, 2003).

6.3.1.2 Speech presentation. Speech alone should not be the sole means of providing alarm and alert information (O'Hara et al., 2002).

6.3.1.3 Nature of signals. Voice signals **shall** consist of a brief, standardized speech signal (e.g., a verbal message) to identify the specific condition and suggest an appropriate action (Ahlstrom & Longo, 2003; DOD, 1999).

6.3.1.4 Presentation of voice signals. Voice signals should be preceded by an initial non-speech alerting signal to attract the user's attention, particularly if verbal messages are used for other types of information as well as alarms or alerts (Ahlstrom & Longo, 2003).

6.3.1.5 Acknowledging signals. The system should require that users acknowledge spoken alarm or alert signals (Ahlstrom & Longo, 2003).

6.3.2 Intensity.

6.3.2.1 Verbal signals. Verbal signals for critical functions **shall** be at least 20 dB above the speech interference level at the operating position of the intended receiver but **shall** not exceed 90 dB(A) (Ahlstrom & Longo, 2003; DOD, 1999).

6.3.2.2 Speech intensity. Speech intensity should be appropriate to the expected ambient noise environment, with a signal to noise ratio of at least 5:1 (Ahlstrom & Longo, 2003).

6.3.3 Word selection.

6.3.3.1 Word choice. The words used in verbal signals **shall** be intelligible, concise, and appropriate to the task and the information presented (Ahlstrom & Longo, 2003).

6.3.3.2 Words to avoid. To the extent possible, words that rhyme with other words or that sound similar in other ways should be avoided if these other words might be used in the same context and, therefore, possibly be confused with the original words. It should be remembered that people who wear hearing aids hear words differently from people with normal hearing (Ahlstrom & Longo, 2003; ASTM International, 2007).

6.3.3.3 Formal words. Formal or correct words should be used; slang, jargon, and colloquial words should be avoided (Ahlstrom & Longo, 2003; ASTM International, 2007).

6.3.3.4 Alphabetic information. Alphabetic information should be presented using a phonetic alphabet that uses words like *Alpha*, *Bravo*, and *Charlie* rather than the letters A, B, and C (Ahlstrom & Longo, 2003; ASTM International, 2007).

6.3.4 Presentation.

6.3.4.1 Start message at beginning. The signal, when activated, **shall** always start at the beginning of the message (Ahlstrom & Longo, 2003).

6.3.4.2 Average talker. Spoken messages should sound like an average talker from the user country without a regional dialect (Ahlstrom & Longo, 2003).

6.3.4.3 Distinctive voices. When different categories of voice signals are used, a different, distinctive voice should be used for each category of data (Ahlstrom & Longo, 2003).

6.3.4.4 Content. Spoken messages should be brief, informative, and to the point (Ahlstrom & Longo, 2003).

6.3.4.5 Message structure. The structure for verbal alarms and alerts **shall** be

a. general heading such as the system or service involved;
b. specific subsystem or location; and
c. nature of emergency (Ahlstrom & Longo, 2003).

6.3.4.6 Word characteristic prioritization. Words used in a verbal message should be selected based on intelligibility, descriptiveness, and conciseness, in that order (Ahlstrom & Longo, 2003; DOD, 1999).

6.3.4.7 Type of voice. The voice used in recording verbal signals may be male or female (male is preferred) and **shall** be distinctive, mature, without dialect, and presented in a formal, impersonal manner (Ahlstrom & Longo, 2003; ASTM International, 2007; DOD, 1999).

6.3.4.8 Delivery style. Voice signals **shall** be presented in a formal, impersonal manner (Ahlstrom & Longo, 2003; DOD, 1999).

6.3.4.9 Repetition. Critical alarm and alert signals **shall** be repeated with not more than a 3-second pause between messages until the condition is corrected or overridden by the user (Ahlstrom & Longo, 2003; DOD, 1999).

6.3.4.10 Speech processing. When a signal must be relatively intense because of high ambient noise, peak clipping may be used to protect the listener against auditory overload (DOD, 1999).

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7. Requirements for Tactile Presentation of Alarms and Alerts

7.1 Use. If tactile signals are used, they should be of such amplitude as to be detected by the part of the body being stimulated, and they should be delivered by an apparatus that will always be in contact with the body (DOD, 1997).

7.2 Coding. Tactile signals **shall** also be coded so as not to be misconstrued as a normal vibration of the equipment or workstation (DOD, 1997).

7.3 Prior approval. Any use of tactile signals should have prior approval by the acquiring organization (DOD, 1997).

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APPENDIX A

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APPENDIX B

Acronyms

ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
cd/m^2	candela per meter squared
CIE	Commission Internationale de l'Eclairage (International Commission on Illumination)
dB	decibel
dB(A)	decibels measured on the A-weighted scale
DOD	Department of Defense
FAA	Federal Aviation Administration
fL	foot-Lamberts
Hz	Hertz (cycles per second)
msec	millisecond
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
nm	nanometer
OCC	Operations Control Center
SOC	Service Operations Center
SPL	sound pressure level
TO	Technical Operations
TRACON	Terminal Radar Approach Control
WJHTC	William J. Hughes Technical Center

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APPENDIX C

Alarms in the Technical Operations Environment

Researchers from the Human Factors Division at the Federal Aviation Administration William J. Hughes Technical Center extracted the frequency and periodicity characteristics for a number of alarms and alerts found in the Technical Operations environment (Ahlstrom & Panjwani, 2003). In Table C-I, we provide this information for the Air Route Traffic Control Center (ARTCC) Service Operations Centers (SOCs). Table C-II shows this information for the Terminal Radar Approach Control (TRACON) SOCs. Note that these tables do not contain all of the alarms and alerts, nor will all of the systems be found at every facility. The purpose of this appendix is to provide some information regarding existing systems so that designers of new systems will not design alarm and alert signals that might appear similar or might easily be confused with existing signals. Ideally, the signal should convey information to the listener about the criticality (urgency) of the situation indicated by the alarm or alert. One characteristic associated with perceived urgency is the interpulse interval. A shorter interpulse interval is associated with increased perceived urgency.

TABLE C-I. **Alarms and alerts found in ARTCC SOCs**

Alarm or Alert	Predominant Frequency (Hz)	Periodicity
CTAS alarm	700 – 1,000	Sounds like dripping faucet: 80 ms of tone followed by 3 seconds of silence.
DARC SONA	2,700	Continuous, single-tone.
DAS-RSD coded time source alarm	Composite	Voice alarm.
DAS-RSD enhanced direct access radar channel alarm	Composite	Voice alarm.
DAS-RSD environmental control systems alarm	Composite	Voice alarm.
DAS-RSD flight service data processing system alarm	Composite	Voice alarm.
DAS-RSD halon alarm	Composite	Voice alarm.
DAS-RSD high capacity voice recording alarm	Composite	Voice alarm.
DAS-RSD host alarm	Composite	Voice alarm.
DAS-RSD national airspace data interchange network alarm	Composite	Voice alarm.
DASD	2,500	A 100 ms beep followed by 90 ms of silence, repeating.

(table continues)

TABLE C-I. **Alarms and alerts found in ARTCC SOCs** - Continued

Alarm	Predominant Frequency (Hz)	Periodicity
DCCR alarm	4,300	Repeating, single-tone, sinusoidal: 100 ms of alarm followed by 900 ms of silence.
DSR keyboard error alarm	700	Single-tone alarm.
DSR M&C-E alarm	3,000	Rapidly repeating high-frequency beep: 100 ms of alarm followed by 50 ms of silence.
DSR M&C-H and M&C-CH continuous alarm	1,400	Repeating, double beep alarm: 200 ms of alarm followed by 100 ms of silence; then 200 ms seconds of alarm, again, followed by 300 ms silence; then repeat.
DSR printer alarm	6,220	High-pitched beep, repeats until paper is loaded.
Fire alarm	3,382	A 500 ms beep followed by 500 ms of silence, repeating.
G3 processor SONA	2,950	Rapidly repeating, single-tone: 100 ms of alarm followed by 70 ms of silence.
G3 terminal	3,200	Continues until acknowledged.
G3 printer beep	3,240	Repeating, single-tone: 250 ms of alarm followed by 150 ms of silence.
G3 processor power	2,870	Continuous, single-tone.
High capacity voice recorder alarm	2,800	Continuous, single-tone.
NADIN I concentrator alarm	3,020	Repeating, single-tone alarm: 200 ms of alarm followed by 200 ms of silence.
VSCS AC power cutoff switch	Composite	Continuous, 2-tone alarm.
VSCS class 1 alarm	985 2,950	Alternating, 2-tone alarm where the lower frequency tone is followed by the higher frequency tone.
VSCS class 2 alarm	1,980	Single-tone, continuous high-frequency alarm with a reverberating quality.
VSCS computer chirp	Composite	Continuous, 2-tone alarm.
VTAB class 1 alarm	Composite	Repeating, multi-tonal alarm: 200 ms of alarm followed by 100 ms of silence.
VTAB class 2 alarm	Composite	Two-tone chime that fades out and then repeats, 1.3 seconds of alarm (including fade-out) and next alarm begins.
VTAB class 3 alarm	755 3,090	Continuous, single-tone made by combining the two predominant frequencies.

TABLE C-II. **Alarms and alerts found at the TRACON SOCs**

Alarm	Predominant Frequency (Hz)	Periodicity
ARTS IIIA conflict alert	1,360	Repeating, single-tone: 90 ms of alarm followed by 80 ms of silence.
ARTS IIIA minimum safe altitude warning	1,360	Repeating, single-tone: 90 ms of alarm followed by 80 ms of silence.
ARTS IIIE conflict alert	2,800	Repeating, single-tone: 250 ms of alarm followed by 30 ms of silence.
ARTS IIIE minimum safe altitude alert	2,800	Repeating, single-tone: 250 ms of alarm followed by 30 ms of silence.
ARTS IIIE scatter	2,730	Repeating, single-tone: 140 ms of alarm followed by 90 ms of silence.
ASR-9 SCIP	2,800	Continuous, high-pitched, single-tone.
ASR-9 power alarm	2,900, 55	Two alternating tones: 580 ms of 2,900 Hz followed by 600 ms of 55 Hz.
DVRS remote	3,100	Continuous, high-pitched, single-tone.
FOTS	800, then voice	Four bells: 800 ms each, separated by 150 ms, and 380 ms pause followed by female voice stating "(Location) Fiber Optic Equipment alarm."
ICSS computer alarm	900	Repeating, single-tone beep: 200 ms of alarm followed by 200 ms of silence.
ICSS fuses SONA	2,800	Rapidly repeating, single-tone beep: 100 ms of alarm followed by 70 ms of silence.
ILS panel alarm	50	Repeating, 685 ms beep followed by a 500 ms inter-stimulus interval.
ILS (Mark 20) alarm	50	Continuous tone.
LLWAS alarm	610	Rapidly repeating, triple-beep: 70 ms of alarm, 50 ms of silence, 50 ms of alarm, 50 ms of silence, 50 ms of alarm, 30 ms of fade-out, 250 ms of silence, and the cycle repeats.
Mode S computer alarm	2,190	Repeating, single-tone.
Multi-channel voice recorder alarm	2,395	Rapidly repeating, single-tone beep: 200 ms of alarm followed by 250 ms of silence.
RDVS alarm	3,200	Continuous tone with a secondary repeating lower frequency tone.
RDVS computer	2,000	Repeating, single-tone beep: 50 ms of alarm followed by 1 second of silence.

In addition to extracting the frequency and periodicity characteristics, the researchers also measured the sound pressure level (SPL) at different locations around various field sites. Because some work areas are busier than other work areas, the noise levels also varied. Therefore, researchers estimated the workload levels while they obtained the measurements. Even at normal workloads, the ambient environment was fairly quiet, ranging between 52 and 63 dB(A). Table C-III shows the average of the SPL measurements.

TABLE C-III. **Average ambient sound levels at Technical Operations field sites**

Site	Average SPL dB(A)
Atlantic OCC	57.8
Pacific OCC	61.2
Atlanta ARTCC SOC	56.5
Chicago ARTCC SOC	56.5
San Diego ARTCC SOC	55.3
Seattle ARTCC SOC	53.3
Atlanta TRACON SOC	56.7
Chicago TRACON SOC	52.0
San Diego TRACON SOC	59.5

These values provide some guidance on how to set the intensity of the auditory alarms and alerts in work areas. Human factors design criteria indicate that auditory signals should exceed the ambient noise level by at least 10 dB(A). However, the user should be able to adjust the volume of the audio signal depending on the operational situation and the safety of personnel.

APPENDIX D

Considerations for Visual Presentation of Alarm and Alert Signals

Service Operations Center (SOC) operating environment

In order to understand human factors input to the Technical Operations (TO) work environments, it is helpful to understand what the Service Operations Centers (SOCs) work environments are like. TO is not a homogeneous environment. Within TO, specialists at SOCs monitor many systems within a large control room. TO specialists at these facilities use status coding as a primary means of obtaining information while monitoring systems in their domain. There are two general types of SOCs: Air Route Traffic Control Center (ARTCC) SOCs and Terminal Radar Approach Center (TRACON) SOCs. The lighting levels and equipment monitored are different for these two types of SOCs and, in fact, may be different within a SOC type.

The TO area is often colocated with Air Traffic operations at ARTCC SOCs. Because they are colocated with Air Traffic operations, the ambient lighting levels are low. The work area is generally small, as little as 400 square feet at some facilities. This workspace contains 35 to 40 computer processing units and monitors for the control of up to 25 different computerized systems. The work area also contains hard-wired panels and displays of environmental, security, and performance information.

Nearly every ARTCC SOC has at least one wall of computer monitors stacked (three high) above workstations due to the size limitations of the workspace. Therefore, to monitor and control system information displayed on the monitors that are located on the middle and upper levels may require the shorter personnel to use a step stool to see the information.

Generally, specialists at the TRACON SOCs monitor and control fewer computerized systems than the specialists at ARTCC SOCs. The specialists at the TRACON SOCs are responsible for 12 to 18 computer systems compared to the 25 to 30 at ARTCC SOCs. SOCs at TRACONs are frequently colocated with Air Traffic Control (ATC) operations. In these situations the work area is dark, even darker than the ARTCC SOC work areas. But, TRACON SOCs that are separate from the ATC work floor are well lighted. Generally, the lighting levels are similar to the lighting levels of a normal office environment. As in the ARTCC SOCs, there is a substantial amount of information conveyed at TRACON SOCs via hard-wired displays. Thus, there is less stacking of monitors; when it is necessary, the stacks are no more than two rows high.

Impact of aging on displays used in a Technical Operations environment

As people age, the ability to divide attention over multiple on-screen tasks diminishes. People in their twenties can perform up to four tasks, especially if the operator is familiar or experienced with some of the tasks. People in their fifties require effort to maintain two tasks simultaneously.

Additionally, the ability to maintain attention, even with stimulating tasks, begins to diminish as people age. With decreasing ability to divide attention, users become increasingly reliant on status codes to attract their attention to items needing attention. Thus, the effective use of status codes to direct user attention becomes increasingly important.

Integrated displays

The benefit of an integrated display for the presentation of alarm and alert messages is that it allows a single location for message presentation. The integrated display can (a) present concise alphanumeric messages of alarm or alert situations to the operator, (b) present information about the alarm or alert urgency level to the operator, (c) recommend corrective actions to the operator, and (d) present feedback to the operator when faults are corrected.

Visual symbols

Visual symbols are pictorial representations that stand for or suggest something else. The use of symbols in automated systems has become progressively more common. With the increase in computerized equipment, TO specialists are exposed to more and more varied symbols. The number of systems remotely monitored and controlled is continually increasing. When a system is remotely monitored or controlled, the status and other important information are often represented to the user as an alphanumeric or pictorial symbol on a display screen. TO personnel are responsible for many different systems created by different organizations, therefore, the TO specialists who monitor and control the systems will encounter an increasing variety of visual symbols.

1. Symbol use

TO equipment and systems use symbols for many different reasons, mainly for the advantages they provide over text displays. Symbols can save space, speed visual search, and facilitate recognition and recall. Well-designed symbols can enhance user performance, attract attention, and convey information quickly. In general, users can recognize well-constructed symbols more rapidly and accurately than written words, and using well-designed symbols can reduce time and confusion when dealing with alternative systems, control devices, and displays.

However, using visual symbols to convey information is not always advantageous. When there are too many symbols on a display, or in a work area, this can affect a user's memory and cause confusion. Often symbols are not a viable option due to equipment limitations, such as minimal display space or low screen resolution. Poorly designed symbols or inappropriately used symbols can cause more harm than good.

2. Take an integrated approach

To maximize the benefits of symbol use, it is important to take an integrated approach to the use of symbols. This approach involves not only looking at the number of symbols on a particular system, but also looking across the systems to which a single user is exposed (including aspects

of the physical environment that might impact the effectiveness of symbols). The number of symbols with which a user is required to interact with (size of the symbol set) can affect user performance. The demand that's placed on the operator's memory increases as the number of symbols increases – leading to decreased user performance.

3. Consider the target audience

To ensure symbol effectiveness, it is important to consider the characteristics of the target user. These characteristics can include the amount of system training acquired by the users, the users' past experiences with interfaces and symbols, as well as whether the users' work at a fixed position in front of the display or move around. Past experience with symbols can influence the interpretation of new symbols, as users may already associate specific meanings with those symbols. Users that are not positioned at a fixed distance from the display are likely to need visual symbols to convey critical information at larger viewing distances. Thus, for users who move around, symbols need to be large and distinct enough to be distinguishable at increased viewing distances. When users must view information from a distance, symbols could be more effective than words. When designing or standardizing symbols, it is critical to capture this kind of information about the users and the environment in which the symbols will be presented.

Key components of a symbol

Most symbols consist of a pictorial image surrounded by a shape with a distinct border. Some symbols also include a text label. Each of these components is critical to effective symbol design. The pictorial image should be an effective metaphor, providing an analogy from which the user can determine what is being represented by the symbol or inferred by the behavior of the system(s) that will result from activating the symbol. Using different background shapes behind a pictorial image has proven to be effective for warning and information symbols. Although shape coding is not used as frequently in the realm of computer symbols in office environments, it can be an effective method of increasing the amount of information conveyed to the user without increasing the number of overall symbols. Coding conventions, such as color and flashing, are components of a symbol. As the operators interact with the symbol, coding conventions are often employed to indicate that the item represented by the symbol requires user attention.

More complex symbols can take a greater time in order to respond. Symbols that are drawn with too much detail or with lines that are too thin may not be distinguishable when shown at the smaller sizes, which are necessary for many graphics. Additionally, simple symbols (distinguishable based on only a few features) facilitate visual search more than complex symbols do. Thus, the graphics on symbols should be simple – with lines thick enough to ensure that the symbols are distinguishable at all of the resolutions that it will be viewed. This would imply that as long as the users can distinguish the symbol, it is preferable to use the simpler representations with a lesser degree of realism.

By standardizing components of a graphic, the user can assign meanings to a class of objects, transfer existing knowledge, reduce training time, and reduce memory load. Simple components

can be combined in a symbolic language. Any standardization effort should employ representative users to identify similarities and differences between the symbol objects, functions, and concepts.

Text and labels

Although the use of graphic symbols can save space, speed search, and improve recall and recognition if they are well designed, the use of symbols whose meanings are not clear can make a system more difficult to use. If it is difficult to clearly represent the function with a graphic, use a text label with the graphic or replace the graphic. If some ideas can be represented as symbols but other ideas need to be represented as words, words should be used for the entire array.

Some numbers and letters used in labels are easily confusable, such as "Z" and "2" or "O" and "0." If both numbers and letters are used in a label, it is imperative that the letters and numbers are easily distinguishable.

For legibility, labels should be displayed consistently. Use all capitals or use mixed cases with the first letter of the word capitalized. The justification behind using all capital letters is to maximize the size of the text to meet legibility height requirements. But, for speed of recognition, there is no clear evidence that favors using all capital letters over capitalizing the first letter. There is also no evidence that this is detrimental. Many of the text boxes contain acronyms for monitored systems. The letters in these acronyms are all capitalized, intentionally. For consistency, it makes sense to use all capital letters in the text if some of the labels will be in all capital letters due to acronym usage.

Considerations when using color as a coding method

When used appropriately, color can be helpful in decreasing response time and aiding visual search for information, particularly in dense displays (if the user knows the color of the target). When the user knows the target color, the search time depends on the number of symbols that are the same color as the target. Search times are longer, however, for targets in multicolored displays. In general, search times increase as the number of items on the display increase. Color coding provides the most benefit with increased display densities. At high densities, color coding is much more effective than shape, numeric, and symbolic coding (but is only slightly more effective than these methods at low densities). Care must be taken to ensure that the coding is consistent with the user tasks and that color is not overused as a coding method. Task-irrelevant use of color or using more than seven colors can cause performance decrements.

Color can also promote user satisfaction. Users often express a preference for color as a coding method, even in instances when it does not improve performance. For example, users may request that the designers use color even if it is not appropriate for the application, which may inadvertently hinder performance.

The use of color as a coding method can be complicated. Decisions need to be made concerning how many colors to use as well as what colors to use. This is confounded because the perceived color can be influenced by many factors such as the color of the background, the size of the stimulus, and the viewing angle. To complicate matters further, the perception of color may vary because most of the population perceives color differently due to color deficiencies, a person's age, ambient lighting, and nearby colors that can influence a person's perception. Therefore, color should be used only as a redundant coding technique.

The trichromatic theory of color vision proposes that color vision is based on three different types of color receptors that have three different spectral sensitivities (red, green and blue). These different receptors react differently to the wavelengths of light entering the eye to result in the perception of color. Individuals who have deficiencies in (or are missing) these receptors perceive colors differently. These individuals may have difficulty in discriminating between certain colors. Highly saturated colors in particular can be difficult for color deficient people to differentiate, particularly saturated red. For this reason, color should be used as a redundant coding method. For example, people who cannot distinguish between hues of red and green could use differences in brightness to provide a clue to the color; color and brightness normally covary.

Highly saturated colors, particularly from different parts of the spectrum (e.g., saturated red and blue, and saturated red and green), can cause unwanted visual effects. Pure blue should also be avoided, because it can be difficult to read or resolve if it is presented on small objects, text, or thin lines because of a lack of blue sensitive cones necessary for resolving fine details. Blue can also be problematic for older adults, especially in combination with shades of yellow. The contrast between a symbol and background (or text and background) should be sufficient to enhance color perception, to perceive image resolution, and to ensure readability of text.

Even individuals who have normal color vision will sometimes misperceive the color of an item. The perception of color depends not only on the spectral composition of the light source, but it also depends on the brightness of the light source, the size of the image, the location in the field of view (central vs. peripheral), the color of the background, and the ambient illumination conditions.

Simultaneous color contrast will cause a gray material surrounded by red to appear greenish, whereas the same gray material surrounded by blue will appear yellowish. When a symbol color is surrounded by another color, the symbol color tends to shift in appearance toward the complementary color of the background. This may be lessened by edging the tones with black or white lines. The color of the stimulus may be misperceived depending on the color of the background. One study looked at the classification of colors against different colored backgrounds and found that the largest shifts in appearance and largest deviations occurred for red and blue backgrounds. Researchers found that a lack of strong chromatic induction effects when the test and background were widely separated in the chromaticity diagram (Ahlstrom & Muldoon, 2004). The highest degree of confusion was between pink and purple. With a red surround, certain hues were labeled purple, but with a blue surround the same hues were labeled pink. These are near the boundaries of the color region, leading to the recommendation that

colors that must be reliably classified should not be located near the boundaries of the color region based on CIE charts.

The perception of color differences is also influenced by the size of the image. Color discrimination is impaired for smaller symbols or character sizes. Smaller objects tend to appear less saturated and may appear to shift in hue relative to larger objects. Called small field tritanopia, this effect causes green-yellow objects to appear white, objects above 575 nanometers (nm) to appear yellow-red, and objects below 575 nm to appear blue-green. As colored stimuli become smaller, they lose their color in this order: blue, red, and then green. Blue images of less than 15 minutes of arc will appear achromatic. Cyan and yellow are difficult to distinguish for symbols less than 30 minutes of arc; therefore, users should not have to discriminate small areas based on color alone.

Color coding can be affected by the visual-field location of the stimulus. The widest field of view (and shortest response times) are for white stimuli, whereas the narrowest field of view (and longest response times) are for red. In general, peripheral vision is poor for detecting targets, especially if the targets are small.

Changing the intensity of colors can change the way that the color is perceived. Increasing the intensity of colors will cause colors with dominant wavelengths above 510 nm to shift toward yellow, and those with dominant wavelengths below 510 nm to shift toward blue. Perceptually, this shifting can result in the brighter items being perceived as more important than the less bright items.

Scheduled out-of-service or intentional off-line status should be coded gray; it should not be coded red. Red should be reserved for items needing immediate user attention, which is not the case here. If gray is unavailable as a color choice, blue would be a secondary choice for coding this item. However, the user should still be able to see the status colors associated with subsystem and component status. If the system is taken off-line for maintenance or training, it may be beneficial to indicate this status by a letter code rather than by a color code.

Influences of the background on the choice of coding

Positive polarity (light backgrounds with dark symbols or text) displays have the advantage of suppressing reflections. However, with positive polarity, refresh rates must be high enough to suppress noticeable flicker (100 Hz should eliminate flicker for most populations). Most modern computer display monitors have refresh rates of 100 Hz or greater. Advantages of having positive polarity displays include better visual acuity, increased depth of focus, better color discrimination (allowing more colors to be used), less reflections, accommodation, increased performance, and fewer errors.

With negative polarity (dark backgrounds with light symbols or text) displays, ambient lighting has to be low to minimize reflections, causing a lower visual acuity and less depth of focus due to a larger pupil size. It may also impact accommodation. Negative polarity displays are sometimes recommended for giving the best color discrimination on electronic displays.

A gray background can be a reasonable compromise between the two alternatives. A gray background is better than a black background for learning and remembering color-coded information. However, a gray background can cause a decrease in contrast, so it should be tested in realistic environments before being used.

The users' visual task, as well as objects in the environment, will influence the decision on whether to use a black, white, or gray background. If displays differ vastly in brightness, the users' pupils must change substantially when looking from one display to another. Users may experience a loss of performance or discomfort if there are differences in adaptation levels between a display and other fixation points such as a keyboard. User response times to targets are significantly greater after being exposed to a pretest pattern of brighter luminance.

Ambient lighting effects on color use

Some TO environments are colocated with Air Traffic operations, especially at ARTCC SOC facilities. These environments tend to be dimly lit. Conversely, TRACON SOCs are more brightly lit and specialists have direct control of their lighting. The specialists at the TRACON SOCs tend to adjust lighting to levels similar to that of a normal office environment. Additionally, information on TO systems may be viewed from different angles or distances depending on the facility.

The chromaticity of colors, as well as the luminance contrast, changes as a function of ambient illumination. Under higher ambient illumination, colors shift in hue and become desaturated. Ambient illumination can also affect response times. At lower luminance levels, response times to wavelengths in the blue-green spectrum are shorter. At high ambient illumination, response times to red are faster than for either green or yellow targets. At low levels of ambient illumination, symbol luminance must be reduced to maintain dark adaptation; however, colors cannot be reliably differentiated if reduced to less than 3 cd/m^2.

Shape coding

The use of shape coding facilitates the recognition of warnings and can help support the user's ability to discriminate between categories of icons. It should be recognized that with increasing numbers of shapes, the learning time increases and the ability to recall the meaning decreases. The ability of users to distinguish between shapes, the comprehensibility of shapes, and established meanings for the shapes used in TO systems is unknown and should be determined as part of any standardization process.

False alarms and alerts

The trade-off between informing the user to off-normal conditions and the creation of nuisance alarms and alerts needs to be considered when determining appropriate alarm and alert setpoints. A system that is designed to minimize misses at all costs is likely to have frequent false alarms and alerts. However, automated systems that have frequent false alarms and alerts are unlikely

to be trusted, or even tolerated. When there is low probability that the alarm or alert is a true alarm or alert, users tend to ignore, mistrust, or turn off alarms and alerts. Setting the false alarm or alert threshold requires careful evaluation of the trade-offs between missed signals and false alarms and alerts, including not only the decision thresholds at which the system is set, but also the probabilities of the condition to be detected.

It should be noted that when the probability of an event is low, the odds of a true alarm or alert can be quite low for even a very sensitive warning system, causing inevitable false alarms and alerts.

APPENDIX E

Considerations for Audio Presentation of Alarm and Alert Signals

The Technical Operations Environment

It has been noted that Technical Operations (TO) specialists at the Operations Control Centers (OCCs) often sit directly in front of their computers, which minimizes the effect of the layout on alarm and alert signal masking and localization. It was found that auditory signals at the OCC were often disabled. The TO specialists indicated that auditory signals were not prioritized and therefore caused a distraction. They also indicated that because they sit in front of the display, and constantly monitor the displays visually, the visual signals were sufficient to attract their attention.

The TO specialists at the Service Operations Centers (SOCs) indicated that they frequently move around the area. A typical SOC has a work area in the center of the space. The systems that are capable of generating auditory alarms and alerts are located on all sides of the work area. This means that if a TO specialist is working on a system on one side of the work area, alarms or alerts on the other side can potentially be attenuated by sound shadows created by systems and equipment located in the work area. High-frequency sounds tend to have larger sound shadows, whereas low frequency sounds tend to have smaller sound shadows. Hence, it is possible for the user to be located at a distance from an alarm or alert, with equipment between the user and the signaling system.

This could cause difficulty for the localization of the signals. This is a particular concern, as 50 percent of the Terminal Radar Approach Control (TRACON) signals and 36 percent of the en route signals have frequencies between 1,500 and 3,000 Hz. These frequencies may be difficult to localize and hear around obstacles because phase and intensity cues are not effective. Broad-spectrum auditory alarms and alerts are easier to localize and are preferred to pure tones.

Auditory signals in the TO environment

Designers often develop the auditory signals with minimal consideration of the auditory signals already present on the existing equipment. The addition of new systems without taking into account existing systems can exacerbate the situation for TO specialists who already face a multitude of diverse systems. The result can be an overwhelming cacophony of sounds.

Auditory signals serve an important purpose in the TO environment. As TO specialists often move around when they perform their tasks, the auditory signals alert them to conditions that are in need of attention without requiring constant visual monitoring. Auditory alarms and alerts are effective because of their ability to attract user attention. However, if an alarm or alert attracts the user's attention inappropriately, it can be a problem. Incorrect, inappropriate, or overused auditory alarms and alerts can be counterproductive, can cause annoyance, and can negatively

impact the user's ability to perform the job effectively. Auditory signals that are not helpful can be defined as noise. An alarm or alert becomes noise when it does not correspond with the user's current intentions. Noise can impair alertness, cause annoyance, and impact concentration and complex mental activities, leading to a decrease in performance.

The evolution of technology and digitized sound has increased the number and type of potential auditory signals. Auditory signals were once limited to buzzers, bells, and sirens. However, now, the possibilities are almost limitless. Even sounds that do not exist in reality can be synthesized by combining sounds. This does not mean they are the best sounds for a particular system. In fact, the increased number of possibilities for alarm and alert sounds increases the decisions that designers and program managers must make when determining what sounds are optimal for their system.

The characteristics of operational surroundings can greatly affect auditory signals. Background noises such as other equipment sounds can mask alarms and alerts. The distance between the operator and the signal and the presence of items (such as sound absorbing, sound reflecting, or sound generating materials) between the operator's location and the location of the signal can make the signal inaudible to the listener. Sounds can echo off of hard surfaces, and even the ambient temperature can affect the sound. Therefore, it is imperative that an evaluation of signals also takes the environmental factors and the physical characteristics into consideration.

Auditory signals

Research has shown that any increase in noise level above threshold in a workplace tends to increase muscular tension and, as a result, increases the expenditure of energy (Duncanson, 1994). Tasks that require intense mental concentration are adversely affected by sound. TO specialists in a noisy environment are likely to be more quickly fatigued, more nervous, and more irritable than specialists working in a quiet environment. High-frequency sound is more annoying than low-frequency sound, and irregularly variable sounds are more annoying than steady or periodically changing sounds.

The minimum duration signal burst that can be reliably detected by humans is 100 milliseconds (msec). Sounds of less than 200 to 500 msec in duration do not sound loud and often are not perceived over normal workplace ambient noise. Detectability increases as duration approaches and surpasses 500 msec.

Alerting value of signals

Research examined the effectiveness of preceding synthesized voice warning messages with alerting cues, consisting of the simultaneous presentation of an audible tone and a light (Duncanson, 1994). The study was conducted in a high-workload, human-computer interaction task. It was found that if there was only one type of message, the alerting cues served no purpose, and, in fact, lengthened response times. However, if the cues signaled a particular type of message, the absence of a cue resulted in a decreased detection of the message.

Research on the effects of individual sound parameters on perceived urgency indicated that signal level and interpulse interval are important characteristics (Duncanson, 1994). A high sound level and short interpulse interval were perceived similar in urgency to a low sound level and a long interpulse interval. In signal design, sound level is the most important characteristic, followed by interpulse interval (second), and fundamental frequency (third). In order to achieve the highest level of urgency without regard to sound level above ambient, it is suggested that a shorter interpulse interval be used.

Voice (verbal) alarms and alerts

Although there are many benefits to a voice (verbal) alarm or alert, there are disadvantages as well. There will be occasions when TO equipment will be located in the same area occupied by Air Traffic personnel. The equipment designed for the air traffic controller often has voice messaging included as part of its normal operation. This voice messaging coupled with the ground-to-air and ground-to-ground communications creates an environment of continual verbal message traffic.

In these situations, the onset of a TO verbal alarm or alert could be a major distraction. The air traffic controller might seek the source of the voice message, possibly diverting attention from other critical tasks. As the number of TO voice alarms and alerts increases, the air traffic controller could experience an increase in workload, an increase in annoyance, and a loss of situational awareness (further complicating an already complex activity); all contributing to a possible decrease in performance.

Caution is urged before deciding on the use of voice alarm and alert signals. The operational environment needs to be carefully examined, as does the potential impact on all personnel that will occupy that environment.

Sound characteristics

General characteristics pertaining to the selection of loudness, frequency, and use of sound waveforms:

- If the distance to the listener is great, use increased loudness and low frequencies.
- If the sound is to be heard around obstacles and to pass through partitions, use low frequencies.
- If background noise is present, select frequencies lower than that of the background noise, and use several tones differing by an octave.
- To attract attention, modulate the signal to give intermittent “beeps” or modulate the frequency to make pitch rise and fall at a rate of 1 to 3 Hz.
- To distinguish between different alarms and alerts, use different sound waveforms with a pulse frequency between 0.5 and 2.0 Hz, use the same waveform for the same function or purpose (consistently), and use no more than three or four different forms.

Potential issues related to auditory alarms and alerts

The following are some potential issues related to auditory alarms and alerts extracted from the auditory alarm literature. It should be remembered that the severity will be different for different types of facilities (e.g., Air Route Traffic Control Center [ARTCC] vs. TRACON) and every issue will not be relevant to every facility.

1. Alarms and alerts are easily confused

Many alarms and alerts could be easily confused because they sound alike. Alarms and alerts that are too similar in frequency or periodicity can be difficult for the user to differentiate. Alarms and alerts can be designed to be unambiguous by varying frequency, modulation, or both. Alarms and alerts should be separated by at least 400 Hz in frequency. Although people can discriminate frequencies closer than this in a laboratory, the operational environment is more acoustically complex than a laboratory. Alarms and alerts should also differ in periodicity, taking care to avoid continuous signals. Because the human auditory system quickly adapts to continuous auditory stimulation, continuous tones are the most easily confused signals, even if they vary considerably in pitch.

2. Alarms and alerts can be masked

The background noise of the operational environment can easily mask alarms and alerts. This can happen in two major ways. One way is through the positioning of the signals. If the signals are positioned at a distance from the specialists, or if equipment or walls are between the specialist and the signal, signals can be masked, particularly if they are higher frequency alarms or alerts. The equipment in an ARTCC is often laid out over a large area, increasing the possibility of alarms and alerts being masked and unheard. Objects in the environment can significantly impact the absorption and reflectance of an alarm or alert sound, depending on the characteristics of the alarm or alert and the materials present in the environment. The presence of sound absorbing material can reduce the overall SPL and the SPL of reflected sounds. The intensity, duration, and source location of audible alarms and alerts should be compatible with the acoustical environment of the intended receiver. In order for an auditory signal to be heard, it must exceed the listener's threshold of hearing and the masked threshold for the signal in the background noise. Designers should ensure that the characteristics of the alarm and alert sounds are sufficiently different so as not to be confused with sounds present in the environment.

The second way alarms and alerts can be masked is through the similarities between the alarm or alert and the background noise in key characteristics such as frequency. Alarms and alerts should differ in frequency and periodicity from environmental and background noises, including telephone sounds and people talking, so that they are distinguishable. To resolve this issue, it is important to know what types of noise are present in the current environment. Designers should consider the existing background noises and the relation of the user to the position of the equipment. This consideration should include the distance from the equipment and whether equipment or other items will be between the specialists and the alarm or alert sounds. In order

for an alarm or alert *not* to be masked by the background noise, it must be placed at a location where the intended user can optimally perceive it.

Additionally, the natural degradation of human auditory functions with age can exacerbate masking. As specialists get older, their ability to hear different sounds changes, often resulting in marked decreases in the ability to hear high-frequency sounds. One way to ensure operational suitability is to test and evaluate alarms and alerts for usability and user acceptance, using a representative sample of the entire range of the user population.

3. False and nuisance alarms and alerts

Some systems have a tendency to produce false alarms. Grouped with false alarms and alerts are nuisance alarms and alerts, noting that some alarms and alerts frequently sound for systems or equipment for which TO personnel are not responsible or concerned. Alarms and alerts that sound for conditions that do not require user attention cause annoyance and can distract the users from performing their primary tasks. Determining whether an alarm or alert requires action or is irrelevant can take time from other important tasks and can increase workload. False and nuisance alarms and alerts are an obstruction to task performance and often startle the personnel in the area. Specialists usually turn off nuisance alarms and alerts while continuing to watch the display, hoping to find the cause of the alarm or alert. Auditory alarms and alerts should not be present in the operational environment if they do not provide meaningful information to the user. Designers should take steps to minimize false and nuisance alarms and alerts.

4. Simultaneous (multiple) alarms and alerts

Too many alarms and alerts sounding simultaneously can cause confusion or can mask the signal. The extent of the masking that occurs depends on how close the signals are in spectral characteristics, relative loudness, duration, and timing of the sound components. Intermittent signals are less likely to mask other signals than continuous signals.

When possible, alarms and alerts should be organized with the significant alarms or alerts receiving the highest priority. Because systems are often interconnected in the TO environment, multiple alarms could be generated from a single failure. When two or more incidents or malfunctions occur simultaneously, the one with the highest priority should be presented first. It may be necessary to identify the fact that multiple alarms are in the queue.

5. Acknowledging alarms and alerts

A big concern with auditory alarms and alerts is that they are difficult to acknowledge. Although specialists could turn off or acknowledge most alarms, the process was not standard across systems, causing additional cognitive workload for the specialists. All systems and applications should be provided with a simple, consistent means of acknowledging the alarm or alert. The acknowledgment should silence the auditory portion while the specialist addresses the problem. This acknowledgment should not inhibit or slow the response to the condition initiating

the alarm or alert. To the maximum extent possible, the process for acknowledging alarms and alerts should be standardized within and across systems.

6. Locating the source of signals

Localization of a signal can be helpful in determining to what an alarm or alert refers and where to direct attention. Several factors (including the spatial location of the sound sources, echoes, reflections of sound off equipment, and the acoustical characteristics of the sounds themselves) can impact the sound localization of a signal. Multiple echoes and sound reverberations from surfaces in the room can make sound localization difficult. The human auditory system often compensates by suppressing the late arriving waves from the echoes. Sound sources need to be physically separated in order to use auditory localization as an aid.

Alarms and alerts that are in the mid-frequencies (2,000-4,000 Hz) tend to be more difficult to localize. This is because higher frequencies are shadowed by the head, causing interaural intensity differences. These interaural intensity differences are used to localize the source of the signals. The interaural intensity differences disappear around 1,000 Hz. Interaural time differences are critical to localization for frequencies below 1,000 Hz.

The location of the signal in relation to the user can impact localization. Signals that are directly in front or in back of the user's head are more difficult to locate, because phase shifts are difficult to resolve. However, head movements can resolve localization differences due to interaural time or intensity differences. In addition, complex signals with a broader band of frequencies can minimize confusion.

7. There are too many signals to learn

On-the-job training is the primary means of learning the meaning of auditory alarms and alerts. This poses a high risk of confusion for specialists who have fewer years of experience. One prime concern with alarm and alert design is that most signals did not tell what action specialists should take. Perhaps this is why many specialists prefer voice alarms and alerts to tones. Additionally, voice alarms are less likely to be masked by equipment noise.

There are over 20 signals in the TO area of some ARTCCs, far exceeding human factors criteria. Research indicates that people can learn between four and seven alarms reasonably quickly; however, performance decreases dramatically with additional alarms (Ahlstrom & Panjwani, 2003). Additional signals will also slow learning and cause confusion. Efforts should be made to minimize the number of alarms that specialists are required to discriminate. Auditory alarms and alerts should be used only to clarify an event. Auditory alarms and alerts should inform the user of the appropriate action to resolve an event. When adding new alarms or alerts to an environment, designers should consider the number of alarms and alerts that already exist. Designers should consider voice alarms and alerts, where appropriate. Voice alarms and alerts should be tested in an operational environment to determine the appropriateness. As speech is used to communicate among specialists, it is important to ensure that the voice alarm or alert does not preclude verbal communication.

8. There are no audio signals where there should be

This is a problem often found in situations when the TRACON TO work area is colocated with Air Traffic Control specialists (where there are fewer alarms and alerts). It was noted that there were numerous situations where there should be an auditory alarm or alert available to attract the specialists' focus to conditions that required their attention. However, caution should be exercised before adding auditory alarms and alerts to the TRACON area.

9. Alarm and alert effectiveness

There are instances where only visual signals are available without auditory signals. Auditory signals are often a better choice for more critical situations, whereas for less critical situations an auditory signal may be unnecessary and a visual signal would be appropriate.

Auditory signals provide a better probability of detecting malfunctions or conditions that may cause injury or equipment damage. An audio signal should be provided when:

- The information to be processed is short, simple, transitory, and requires immediate or time-based response.
- The use of a visual display might be inappropriate because of overburdening the visual modality, ambient light variability or limitation, user mobility, degradation of vision by vibration, other environmental considerations, or anticipated user inattention.
- The criticality of a response to a visual signal makes supplementary or redundant alerting desirable.
- It is desirable to warn, alert, or cue the user for subsequent or additional responses.
- Custom or usage has created anticipation of an audio display.
- Voice communication is necessary or desirable.

Many TO specialists prefer voice signals more than tonal signals because they clarify the warning condition and subsequent action required of the specialist. In general, voice signals should be used when tonal signals may be too numerous or are likely to be forgotten, and when ambient noise may mask simple tonal signals. The use of voice signals should be tested with representative users and evaluated for usability (including detection and identification), operational suitability, and user acceptance.

10. Testing alarms and alerts

Some alarms and alerts cannot be tested at the workstation (certainly, all alarms and alerts would be tested during developmental and operational testing to ensure proper functioning). Without a test capability at the workstation, the specialists have no way of knowing whether the alarms and alerts are functioning properly.

11. Integrate the audible alarm and alert system where appropriate

An integrated alarm and alert system allows TO specialists to view and acknowledge alarms from a centralized location. A centralized workstation could provide a single alarm or alert on the station and offer visual clues of the problem. The current layout of systems on the floor requires specialists to continuously monitor all the displays, and this could cause the specialist to miss an alarm or alert. Additionally, a single workstation would have the capability to silence all alarms and alerts. The benefits for such a system will minimize localization and masking issues and allow easier acknowledgment of alarms and alerts. If such a system is employed, care should be taken to ensure it is not a single point of failure.

Abstract sounds

All auditory signals, including verbal signals, act as symbols that users must learn and interpret in the light of their operational and task environment. When designers overuse sound, the auditory signals are often ignored and can cause annoyance, interference, or confusion for the system users.

As noted, an effective alarm and alert system must be intelligible and understandable. Many systems use abstract sounds; either simple or complex tones. However, in order to be effective, the abstract sound must be learned and associated with a particular alarm or alert event. The ringing of a doorbell or a telephone or a police or a fire engine siren are examples of abstract sounds that people encounter everyday. Problems can occur when the operator is faced with a large number of abstract sounds. To avoid such problems, it has been recommended that no more than five to eight abstract sounds be used in a set. This recommendation is not to be confused with the provisions of section 6.2.1.1 (which limits the number of sounds to four when absolute identification is required).

Speech alarms and alerts, assuming the speech is intelligible and an appropriate word is chosen, eliminate the need for the operator to learn and interpret the sound(s).

Environmental sounds (everyday sounds, such as a dog barking or rain falling on a roof) that are familiar to the operator can be identified readily, without the need for additional learning. If appropriately paired with alarm and alert events, interpretation of the warning condition is greatly enhanced. Compared to speech signals, environmental sounds are less susceptible to masking by competing sounds, and are more readily identified and interpreted by operators. Research has shown that speech and environmental sounds are easier to learn and retain than are abstract sounds (Stephan, Smith, Martin, Parker, & McAnally, 2006).

False alarms and alerts

The trade-off between informing the user to off-normal conditions and the creation of nuisance alarms and alerts needs to be considered when determining appropriate alarm and alert setpoints. A system that is designed to minimize misses is likely to have frequent false alarms and alerts.

However, automated systems that have frequent false alarms and alerts are unlikely to be trusted, or even tolerated. When there is low probability that the alarm or alert is a true alarm or alert, users tend to ignore, mistrust, or turn off alarms and alerts. Setting the false alarm or alert threshold requires careful evaluation of the trade-offs between missing a signal and generating false alarms and alerts.

It should be noted that when the probability of an event is low, the odds of a true alarm or alert can be quite low for even a very sensitive warning system, causing inevitable false alarms and alerts.

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APPENDIX F

Design Characteristics of an Alarm and Alert System

Key to any system is the design characteristics upon which the system is built. The following list describes some of the characteristics (in an approximate order of importance) that should be incorporated in the design of the alarm and alert system.

- **Security** – The ability to provide security of communications, transactions, and data storage.

- **Modularity** – The ability to add, modify, and remove pieces of the system without the fundamental need to redesign or reprogram the system.

- **Flexibility** – The ability to grow and contract the system as required.

- **Scalability** – The ability to scale the system by the dimensions of transaction volume, data storage volume, concurrent users, and/or total users without the need for fundamental system restructuring and/or replacement.

- **Reliability** – The ability of the system to provide continual "up-time."

- **Portability** – The ability to move applications across the system or to clone the system for concurrent operations, even across differing hardware platforms.

- **Maintainability** – The ease of maintaining, monitoring, and controlling the entire system including hardware, software, facilities, and communication.

- **Connectivity** – The ability for a wide variety of devices, with a wide variety of human interfaces, to attach to the system as required.

- **Simplicity** – The ability for the system to be easily implemented, operated, and maintained.

- **Data Accessibility** – The ability to access data locally and remotely both during normal operations and during system failures.

- **Interoperability** – The ability of a system to work cooperatively between multiple processors of another system. Interoperability allows the user to deliver the product without downloading to the hardware or operating system platform.

- **Adaptability** – The ease of changing the system as requirements dictate.

- **Viability** – The ability of the system to be operated and maintained within available resources. Hardware technology becomes obsolete within 18 months; software is continually being enhanced; the cost of computer facilities and personnel is continually rising. The system should not be hardware or software dependent, but should allow upgrades at any time. Nor should the system require special facilities or dedicated personnel such as computer operators or programmers.

- **Accessibility** – The ability to access the system from a wide variety of platforms, operating systems, access software, and devices.

- **Availability** – The system must maintain high "up-time" availability to the user.