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Auditory Alarms in the Airway Facilities Environment

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November 2003

DOT/FAA/CT-TN04/04

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U.S. Department of Transportation
Federal Aviation Administration

William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

Technical Report Documentation Page

1. Report No. DOT/FAA/CT-TN04/04	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Auditory Alarms in an Airway Facilities Environment		5. Report Date November 2003
		6. Performing Organization Code ACB-220
7. Author(s) Vicki Ahlstrom, ACB-220, and Gulshan Panjwani, Titan Systems		8. Performing Organization Report No. DOT/FAA/CT-TN04/04
9. Performing Organization Name and Address Federal Aviation Administration William J. Hughes Technical Center Atlantic City International Airport, NJ 08405		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Division 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered Technical Note
		14. Sponsoring Agency Code AAR-100
15. Supplementary Notes		

16. Abstract

This report describes a study on auditory alarms in Airway Facilities (AF). There are two parts of the study. The first part of the study presents a baseline of current auditory alarms and the current acoustical environment at AF operational sites. A research team from the William J. Hughes Technical Center visited Service Operations Centers at several Air Route Traffic Control Centers and Terminal Radar Approach Control facilities. They collected data on current AF alarms and the AF acoustical environment, including facility layouts. A researcher then captured and recorded the data, which are summarized. The document also provides a baseline of information for future systems. The second part of the study presents the results of a survey and structured interviews conducted at AF sites. The survey consisted of 15 potential auditory alarm issues that are often problematic in other environments. AF specialists rated these issues for the relevance to their own environments. The research team then followed up with structured interviews to obtain additional information and place a perspective on the issues identified in the rating exercise. Finally, the researchers provide recommendations based on human factors guidelines and research to help resolve these issues for AF specialists.

17. Key Words Auditory alarms Airway Facilities Human factors		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia, 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 64	22. Price

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Executive Summary

As the group responsible for the monitor, control, and maintenance of the National Airspace System (NAS), Airway Facilities (AF) specialists rely on auditory alarms to provide useful information on systems and equipment that are in need of their attention. New tools, systems, and equipment are continuously being added to the NAS. With these new systems and equipment often come new auditory alarms. Unfortunately, these alarms are often designed without consideration of existing systems and equipment or the maintenance environment. This can result in a number of negative consequences, such as masking, alarms causing annoyance, and alarms causing distraction from the primary task.

The first step toward improving the alarm situation for AF is to provide future designers with the larger auditory perspective that they previously lacked. This overview contains information on the acoustical environment in which the alarms will be present and the other alarms that are already present in that environment. This allows the designer to create alarms that are congruent with the acoustical environment and that do not mask or otherwise interfere with the existing alarms. The second step toward improving the alarm system for AF is to analyze the problems associated with auditory alarms today. This will allow designers to avoid these issues in future systems and to address them in current system upgrades.

To achieve these goals, a research team from the William J. Hughes Technical Center NAS Human Factors Group (ACB-220) visited AF operational field sites. At each field site, a member of the team captured layout and environmental information and had the AF specialists rate auditory alarms on the frequency of occurrence and criticality. A researcher catalogued and recorded auditory alarms present at the site. A member of the research team then asked the specialists at these sites to rank the severity of 15 common auditory alarm issues for relevance to their own operational area. Structured interviews with the specialists followed the rankings to further investigate areas where auditory alarms are problematic. The researchers took recorded alarms from the field sites back to the Technical Center for analysis. Analysis entailed identifying the prevailing frequency and periodicity of the alarms.

This document describes auditory alarms found in AF field sites. It provides a baseline of the current AF acoustical environment by cataloging auditory alarms, measuring and mapping the environment in which they are present, and obtaining and providing criticality and frequency of occurrence estimates for each of the current auditory alarms. This document also provides the results of the specialists' rankings and their responses to the structured interviews.

The results of this study are two fold. First, it provides information on the existing AF operational environments, such as number and prevalent frequency of alarms, positioning of equipment, and ambient noise level. Up until this point, there was no clear picture of the existing AF acoustical environment for programs to use when making decisions about auditory alarms. In order to get this type of data, programs would have to conduct field studies that would cost time and money generally lacking in AF programs. Thus, the programs would take a piecemeal approach to development. Taking a stovepipe approach to development is not ideal, yet the financial and time cost of having each program conduct a field study is unrealistic. The data contained in this study will provide programs with a more integrated view of the existing AF environment. Among other benefits, this information will help future programs avoid creating

alarms that are similar to existing alarms, avoid adding unnecessary alarms in places already inundated with alarms and avoid placing alarms in locations prone to masking or difficult to localize. The criticality and frequency ratings of alarms provide important human factors and programmatic information. Alarms that indicate critical situations should be designed to subjectively convey the criticality (urgency) of the situation (Edworthy, 1994). Alarms that are not critical could be considered for visual alarm alone without the auditory portion. Frequency data are important in that, if an alarm only sounds rarely, the specialists may not remember what situation the alarm indicates.

The ratings of alarm issues by specialists provide information on current concerns with auditory alarms. The structured interviews further expanded these ratings. These data will allow for effective targeted improvements to AF operational areas and will allow future programs to avoid situations that are currently problematic, thereby refining requirements development. The researchers addressed the issues that the participants identified by the ratings and the structured interviews using human factors design criteria.

Based on these information-gathering techniques, researchers found that alarms are easily confused, alarms can be masked, and there were not auditory alarms for some systems that need them. In some cases, there were auditory alarms where they are not needed. Additionally, specialists said that there were too many alarms overall, there were too many nuisance alarms, too many simultaneous alarms, and alarms were difficult to localize. The structured interviews added detail to the ratings provided by the specialists and added some additional issues. Additional issues were that alarms are difficult to acknowledge, some alarms were difficult to test, and there was a lack of prioritization scheme for alarms. When asked what additional improvements they would suggest, specialists overwhelmingly said that they would like to see integrated monitoring and an easy way to acknowledge auditory alarms.

1. INTRODUCTION

Properly designed alarm systems are an important and necessary part of human-system interfaces. Auditory signals convey important information or alert the users to an item needing immediate attention, regardless of where the users are currently focusing their visual attention. Therefore, improperly designed alarms or an overabundance of alarms have the potential to negatively impact the users' ability to do their job.

Auditory alarms alert and inform Airway Facilities (AF) specialists about the status of AF systems and equipment. Over the years, as the National Airspace System (NAS) has increased in complexity, new systems and equipment have been added to the existing equipment in the AF operational work areas. Many of these new systems come with their own set of auditory alarms and alerts, bringing more and more alarms and alerts to users who may already be inundated with sounds. Designers often develop these alarms and alerts in isolation without taking into consideration existing alarms and alerts or the needs of the users.

Airway Facilities Operations (AOP) recognized the benefits of properly designed auditory alarms and the potential hazards of inappropriate alarms for AF operations. To address this situation and move toward improved auditory alarms in the future, the Office of the Chief Scientist (AAR-100) sponsored this research project as part of an overall effort to improve key areas of human-computer interaction for AF.

The current study follows the example set forth by studies of other high workload environments. The first part of this study focuses on the auditory alarm issues identified by the AF specialists in the AF environment. The second part of this study examines the physical characteristics of the AF environment and the alarms present in the AF environment.

1.1 Background

AF is the organization that monitors, controls, and maintains the systems and equipment necessary for the smooth operation of the NAS. AF personnel work in several different areas, including Service Operation Centers (SOCs) located in Terminal Radar Approach Controls (TRACONs) and Air Route Traffic Control Centers (ARTCCs), as well as separate AF Operations Control Center (OCCs). As the group responsible for managing the systems, services, and equipment that make up the NAS, AF personnel are constantly monitoring the status of systems and equipment.

For many years, the number of system-specific interfaces used by AF specialists to monitor and maintain the NAS has steadily increased (Department of Transportation [DOT], 1999). This trend is likely to continue, as there are many proposed and planned changes to the NAS in the near future (DOT, 1999; Federal Aviation Administration [FAA], 2001; Wickens, Mavor, & McGee, 1997; Wickens, Mavor, Parasurman, & McGee, 1998). As designers develop new tools for the NAS, new equipment is added to existing environments, leading to an increase in systems that require monitoring and maintenance by AF. Many of these new devices use visual and auditory signals to indicate the status of equipment. Designers often develop the auditory signals on these devices with minimal consideration of the auditory signals already present on the existing equipment. The addition of new systems without proper integration (i.e., taking into account existing systems) can exacerbate the situation for AF specialists who already face a multitude of diverse systems. The result can be an overwhelming cacophony of sounds. There is currently an effort to ameliorate the proliferation of diverse systems by creating national standards for several key areas in AF. One of these key areas is auditory alarms and alerts.

Auditory alarms serve an important purpose in the AF environment. As AF specialists often move around as they perform their tasks, the auditory alarms alert them to conditions that are in need of attention without requiring constant visual monitoring. Auditory alarms are effective because of their ability to attract user attention. However, if an alarm attracts the user's attention inappropriately, it can be a problem. Incorrect, inappropriate, or overused auditory alarms and alerts can be counterproductive, cause annoyance, and negatively impact the user's ability to do his or her job effectively (Fidell & Teffeteller, 1981). Auditory alarms that are not helpful can be defined as noise. An alarm 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 (Grandjean, 1988). An alarm that serves as noise is one example of problems that can occur for auditory alarms within a system (in this case, the AF operational environment as a whole is considered a system).

The evolution of technology and digitized sound has increased the number and type of potential alarms. Alarms were once limited to buzzers, bells, and sirens. However, now, the possibilities are almost limitless. An alarm stored as a digitized sound on a computer can be anything it is possible to record. 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 sounds increases the decisions that designers and program managers must make when determining what sounds are optimal for their system.

The problems with auditory alarms in the AF environment are likely to be similar to those of other high workload environments, such as nuclear power plants, cockpits, and hospitals. Events that trigger alarms are complex, dynamic, and varying in their degree of urgency. A high workload area where auditory alarms and alerts are of concern is in hospitals. The problems with alarms can be at a system level. Hospital operating rooms and intensive care units are faced with an abundance of monitoring equipment (Haas, 1998; Momtahan, Hetu, & Tansley, 1993; Simons, Fredricks, & Tappel, 1997). Much of this equipment comes with alarms and alerts that indicate patient status. The hospital operating rooms and intensive care units are faced with a proliferation of different alarm sounds that may have no clear mapping to importance or consideration of alarms present on already existing equipment. This results in sounds too similar, too many alarms in the same environment, or inappropriate urgency mapping (the alarm sounds more urgent or sounds less urgent than the situation by which it is triggered). Sometimes the problem with the alarm is in the design itself. Poorly designed alarms can be unnecessarily annoying (Haas).

The International Organization for Standardization technical committee that addresses issues in the medical practice came to the conclusion that alarms and alerts had the potential to negatively impact patient safety. Their response was an effort to create standards for alarms and alerts used on the anesthetic and respiratory care equipment (Welyczko & Graeber, 1994) based on auditory alarm signal characteristics and the immediacy of required operator response.

The aircraft cockpit is another high workload environment that is known to have problems with alarms and alerts. The number of alarms and alerts in the cockpit has steadily increased over the years, exceeding the ability of the human users as information processors to process these data (Noyes, Starr, Frankish, & Rankin, 1995). In light of this proliferation of alarm systems, the FAA conducted a study to evaluate the issues related to alerting systems in aircraft (DOT, 1977). The study cataloged the auditory alarms used in the cockpit. It also found inconsistencies in the utilization philosophies, a lack of standardization, and a rapid increase in the number of alerts. Pilots who used this system expressed opinions that the number of alerts needed to be reduced, many alerts were too loud, and alerts should be prioritized with non-critical alerts inhibited during high workload periods.

The characteristics of operational surroundings can greatly affect auditory alarms. Background noises such as equipment cooling fan sounds can mask alarms. The distance between the operator and the alarm and the presence of items (such as sound absorbing, sound reflecting, or sound generating materials) between the operator location and the location of the alarm can make the alarm inaudible to the listener. Sounds can echo off of hard surfaces, and even the ambient temperature can affect the sound. It is important that an evaluation of alarms take into consideration these environmental factors as well as the physical characteristics of the alarms.

1.2 Purpose

This study identified problem areas for alarms in the AF environment and suggests mitigation strategies. The motivation behind this study was to evaluate whether the current auditory alarms met the users' needs and were appropriate, taking an integrated approach by looking across systems. To achieve these goals, the researchers took a two-pronged approach. First, they collected data about the environment in which the alarms were present, including physical characteristics and the alarms themselves. In addition, the researchers captured information about the criticality of response and frequency of occurrence for auditory alarms. Second, they focused on common auditory alarm issues to see what the major concerns were in the AF environment. AF specialists rated the issues based on areas they identified as problematic in other high workload environments as well as their own. This study focuses primarily on the SOCs both in TRACONs and in the ARTCCs.

This study builds upon previous work in the area of NAS auditory alarms by using the William J. Hughes Technical Center (WJHTC) audio alarm database as a starting point for examining the current AF audio alarms and alerts (Ahlstrom & Longo, 2000). This database contains digital recordings and analysis of auditory alarms in the NAS environment, including the associated equipment, the location of the associated equipment, associated visual signals, frequency, and periodicity. The research team validated the information contained within the database against information from the field sites visited. The team recorded signals that the database did not capture and they added them to the database.

2. METHOD

A research team from the WJHTC NAS Human Factors Group (ACB-220) conducted the study. The following sections describe the method they used to achieve these goals.

2.1 Apparatus

In addition to the list of alarms from the auditory alarm database with space for rating of criticality and frequency of occurrence, a confidentiality statement, a list of 15 potential issues with areas to rate each issue, and structured interview questions, the researchers used the following equipment for data collection at the sites:

- One digital camera to verify layout and the position of equipment speakers
- Sound pressure level meter, Radio Shack Realistic Digital Sound Level Meter
- Digital Audio Tape (DAT) recorder with AC adapters and extra batteries, Sony TCD-D8 DAT recorder
- Digital Audio Tapes
- Set of headphones to verify that the DAT recorder is functioning
- Unidirectional microphone and cable, Sure Model SM81
- Omni directional microphone and cable, Radio Shack 33-1070C
- Tape measure to measure distance from the source of the sound to the operator position
- Thermometer to make sure that the operational environments were approximately the same temperature (sound travels slower in colder temperatures)

The digital camera captured layout and equipment data, mainly serving as a backup to notes and sketches that researchers produced. The Sound Pressure Level (SPL) meter measured the SPL of the ambient environment. A digital audio recorder with a unidirectional microphone recorded audio alarms, and an omnidirectional microphone recorded ambient environment data. The researchers used a tape measure to identify precise locations of the sound sources in relation to the operator position.

2.2 Sites

There is no single site that could be classified as a typical AF site. Thus, in order to maximize the applicability of the results by capturing some of the diversity in AF environments, a member of the research team visited 10 sites from different geographical locations. In selecting sites to visit, the researchers wanted to visit facilities from diverse geographical regions. In order to maximize the number of sites they visited per trip, they selected areas with more than one AF facility within near proximity to one another. The sites were

a. Chicago area TRACON and ARTCC,

b. Seattle area TRACON and ARTCC,

c. San Diego area TRACON, (Palmdale) ARTCC, and OCC, and

d. Atlanta area ARTCC, TRACON, and OCC.

2.3 Participants

Participants in the study were the AF personnel working at the sites on the day of the researcher visit. Researchers interviewed 7 people in the TRACON SOCs and 13 people in the ARTCC SOCs. Specialists at the OCCs said that they did not currently have auditory alarms, so the research team did not proceed further with the interviews at the OCCs.

Prior to participating in the study, researchers provided the volunteers with a description of the study (Appendix A) and a consent form (Appendix B).

2.4 Procedure

Upon arrival , researchers obtained a layout of the facility including location of equipment. When this information was not available, they sketched the facility layout. The researcher validated the room dimensions using a tape measure and made annotations to the drawing, as necessary.

The researcher used the digital camera to photograph key components of the room and took the temperature of the room in degrees Fahrenheit. The researcher also recorded facility location and time information and whether the current workload was normal, light or heavy based on the subjective judgments of personnel on duty at the time. They calibrated SPL measuring equipment prior to measurement. They took SPL measurements using the SPL meter on an A weighted scale (OSHA, 2002). They recorded measurements and their exact locations at six locations around the room, with two measurements per point. They took additional measurements at the operator locations approximating the level of the ear and at particularly noisy locations in the room. Using the digital audio tape recorder and an Omni directional microphone, they recorded ambient noise at several locations in the work area, including the operator work position locations. At the time they recorded the ambient noise, they asked specialists to rate the current workload level (defined as how busy the facility currently is) for the facility as low (less busy than normal), normal, or high (more busy than normal). The researchers made the assumption that the level of ambient noise would increase with the level of workload as increased workload for AF would be concomitant with increased number of phone calls, typing, movement, and talk.

Prior to field site visits, the research team conducted dry runs to validate the data collection equipment and recording process at a location in the WJHTC. Team members recorded test signals and ambient noise levels at the dry run location just as if it were a field site location. They processed signals through a computer in the audiometric room at the Research Development and Human Factors Lab (RDHFL) and stored them on a CD ROM. This dry run provided the researchers with critical practice skills and allowed the identification and troubleshooting of any potential problems with methodology or equipment.

Prior to conducting field site visits, the research team developed detailed lists of facility types, equipment, and known alarms. They based these lists on the WJHTC auditory alarm database, which Ahlstrom and Longo (2000) had developed from previous site visits to facilities made for other studies and subject matter expert input.

Once at the field site, researchers identified and cataloged all of the auditory alarms present at the location, using the list of alarms from the auditory alarm database as a starting point (Ahlstrom & Longo, 2000). Because two primary factors that influence the masking of auditory alarms are the frequency and the duration of the alarm signals, the researchers focused more on the frequency of the alarms than the SPL (National Research Council, 1997). The researchers wanted to make the recordings in an operational setting. As setting off alarms can be both annoying to AF and Air Traffic (AT) operations, researchers agreed with management not to set off alarms that were not already captured in the database. Researchers identified but did not record alarms that specialists could not activate or had the potential to impact operations. At each location, a member of the research team asked the AF specialists to activate alarms and alerts associated with equipment (not already captured in the audio alarm database). The researcher measured the distance from the alarm locations to the operator positions, then carefully recorded the signals from a location approximating the position of the operator's head and logged the location of the recording. For operational environments where the users did not have a fixed location, they set up the equipment 10 inches from the source of the alarm and generated the alarm. While the alarm was being recorded, the researcher took a SPL measurement of the alarm. For alarms that were very brief, they generated and recorded the alarm twice. Prior to recording the signal, the researcher tested the equipment to ensure it was functioning properly and took the SPL reading of the ambient noise at that location.

With the digital audiotape of the recorded alarms brought back to the RDHFL, researchers loaded the alarm recordings onto a personal computer and analyzed them to extract alarm characteristics such as frequency and periodicity using Cool Edit software.

The appropriate use of auditory alarms depends on the criticality of the situation that the alarm indicates. Additionally, specialists may forget the meaning of alarms that only occur on rare occasions (infrequently). Thus, researchers asked the specialists at the field sites to rate both the criticality and frequency of the alarms present in the operational environment. This would assist in identifying the human factors characteristics that the alarm should contain, that is, alarms that indicate a more critical situation should perceptually sound more urgent. A researcher asked the specialists to look at a list of alarms and indicate how frequently they deal with each of these alarms (frequency of occurrence) and how immediate the user response must be for each alarm (criticality of response). The participants indicated which alarms were present in their area and provided, for each alarm, a rating of 1 (never) to 5 (always) of the frequency the alarm went off and the criticality of their response with a rating from 1 (Minimally Critical) to 5 (Extremely Critical) to that alarm. Not all personnel were equally familiar with all of the alarms present in the area. Personnel rated only alarms with which they were familiar.

2.5 Survey of Common Auditory Issues

Researchers met with the participants and explained the purpose of the study. They emphasized that the data would be confidential and anonymous and identified only by participant number and not by a name. They then asked the study participants to read and sign a written statement of confidentiality and consent to participation. The researchers asked the participants to rate 15 different potential issues related to auditory alarms extracted from the auditory alarm literature based on areas that Ahlstrom (2003) identified as problematic in other high workload environments (see Appendix C). Possible shortcomings of closed-ended questions are that there is the risk of missing critical issues that fall outside of the defined areas and there is a lack of interpretation on why the participants gave the ratings that they did. In order to overcome these shortcomings, the researchers followed the ratings task with semi-structured interviews (Appendix D) that allowed the users to further clarify and expand on the ratings data. The researchers interviewed the participants expanding on problems with the auditory alarms in their work area.

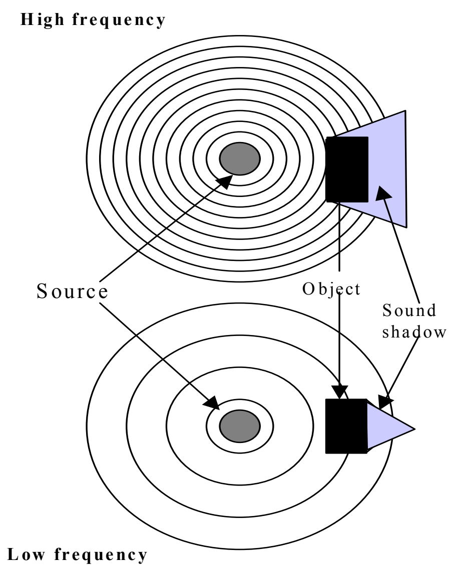
3. RESULTS

The following sections present the results of this study. The first section presents the results of the environmental survey (see Appendix E). The second section presents summarized results and representative comments from the ratings data and structured interviews.

3.1 AF Acoustical Environment

The researchers found that specialists at the OCCs sat directly in front of their computers, which minimized the effects of the layout on alarm masking and localization. All of the auditory alarms at the OCC were disabled. There was only one system at the OCCs that had auditory alarms. The AF specialists said that the auditory alarms were not prioritized and thus caused distraction. They also indicated that because they sit in front of the display, and constantly visually monitor the displays, the visual alarms were adequate to attract their attention.

The AF participants indicated that at the SOCs, they typically move about the area quite a bit. In every site visited, there was some type of work area in the center of the space, with systems capable of generating auditory alarms located on all sides of the work area. This means that if an AF specialist is working on a system on one side of the work area, alarms on the other side can potentially be attenuated by sound shadows created by systems and equipment located on the work area. This is particularly problematic for higher frequency alarms (see illustration in Figure 1).



High frequency sounds are generally attenuated (muffled) by objects that are wider than the wavelengths of the sound, called the sound shadow. Low frequency sounds tend to have smaller sound shadows as illustrated above. (Van Cott & Kinkade, 1972).

Figure 1. Sound shadows created by objects for high and low frequency sounds.

As can be seen from Figures 2 through 10, it is possible for the user to be located at a distance from an alarm, with equipment between the user and the alarming system. This could cause difficulty for the localization of the alarms. This is a particular concern as 50% of the TRACON alarms and 36% of the en route alarms have frequencies between 1500-3000 Hz. These frequencies may be difficult to localize and hear around obstacles because phase and intensity cues are not effective (Ahlstrom & Longo, 2003; Sanders & McCormick, 1993). Broad-spectrum auditory alarms (not pure tones) are easier to localize (Sorkin, 1987) and are preferred to pure tones.

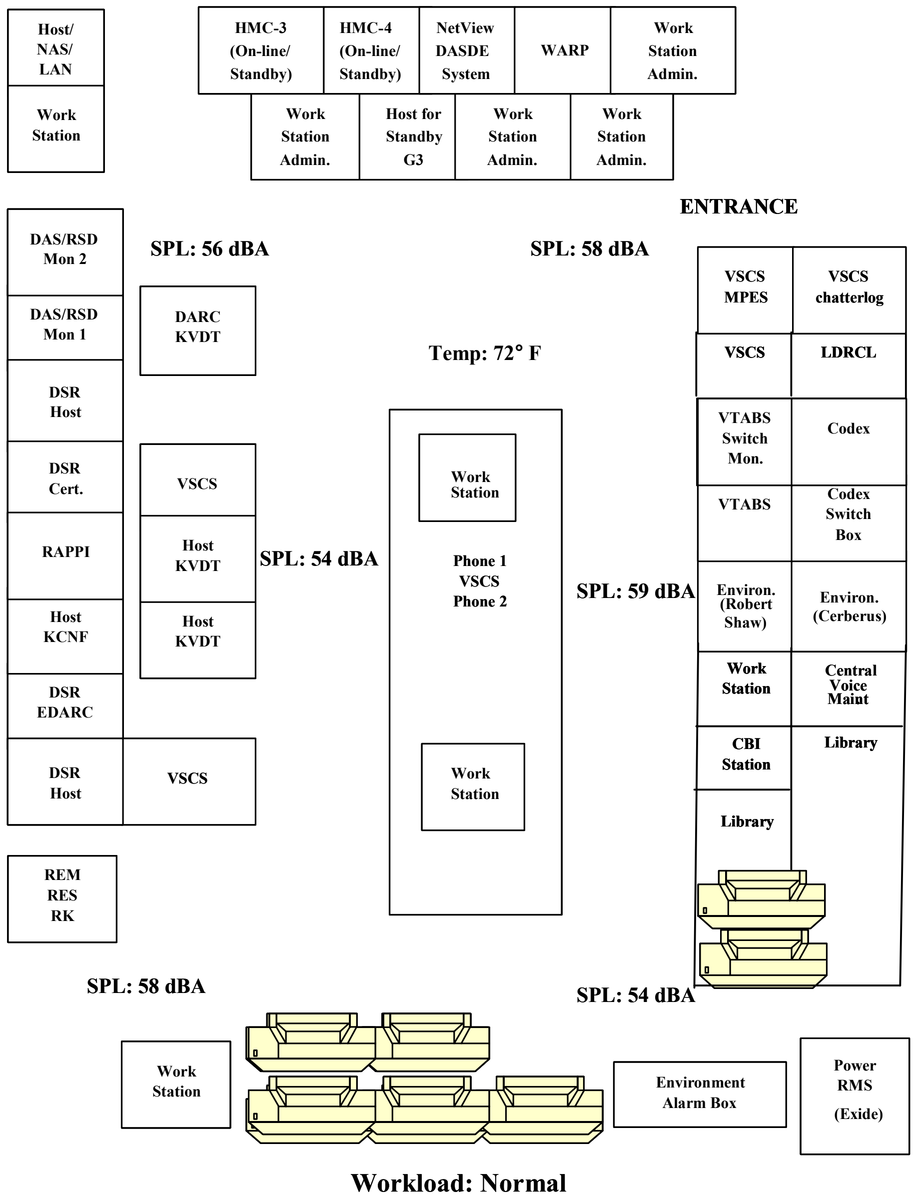


Figure 2. Chicago ARTCC.

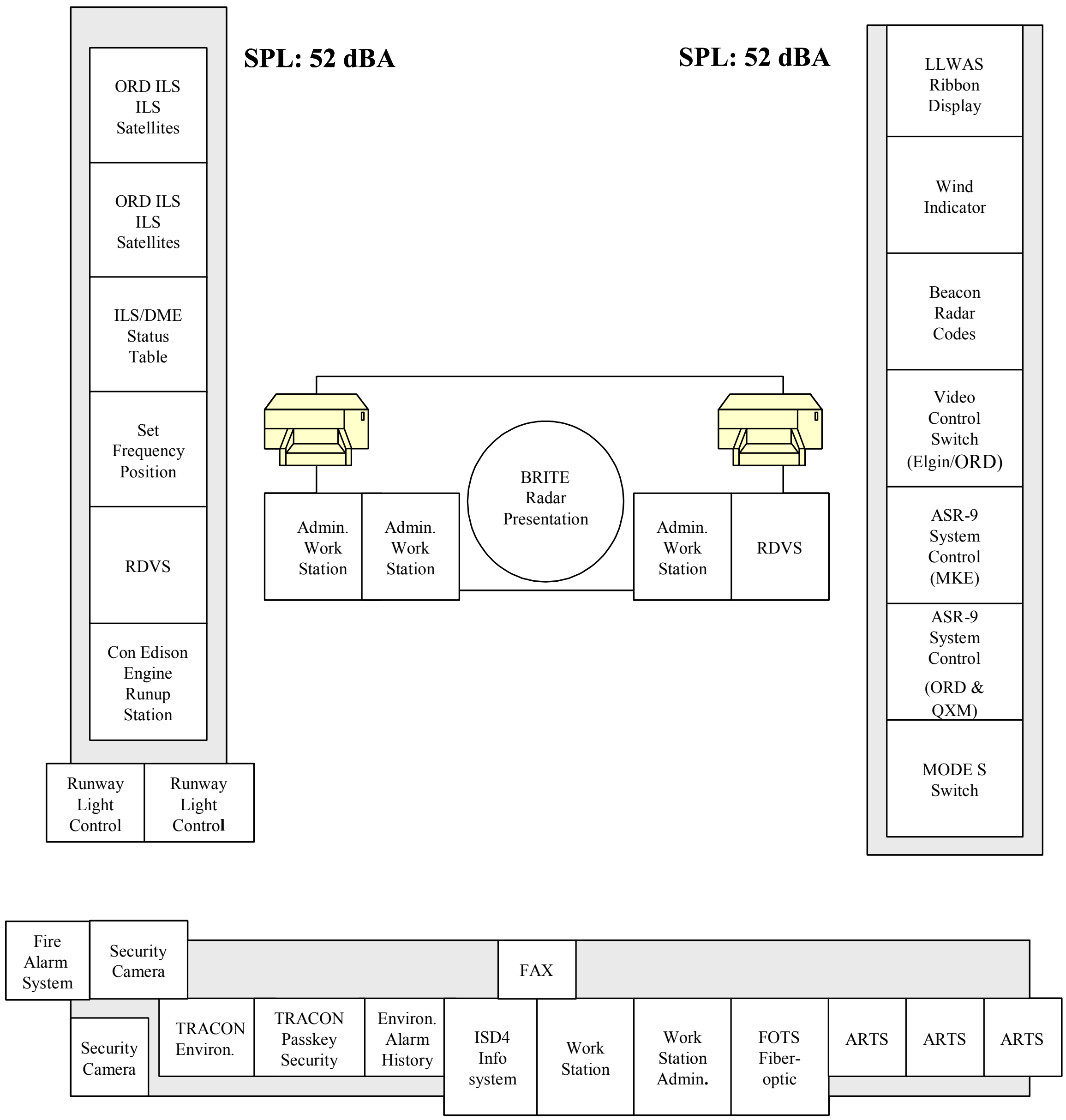


Figure 3. Chicago TRACON.

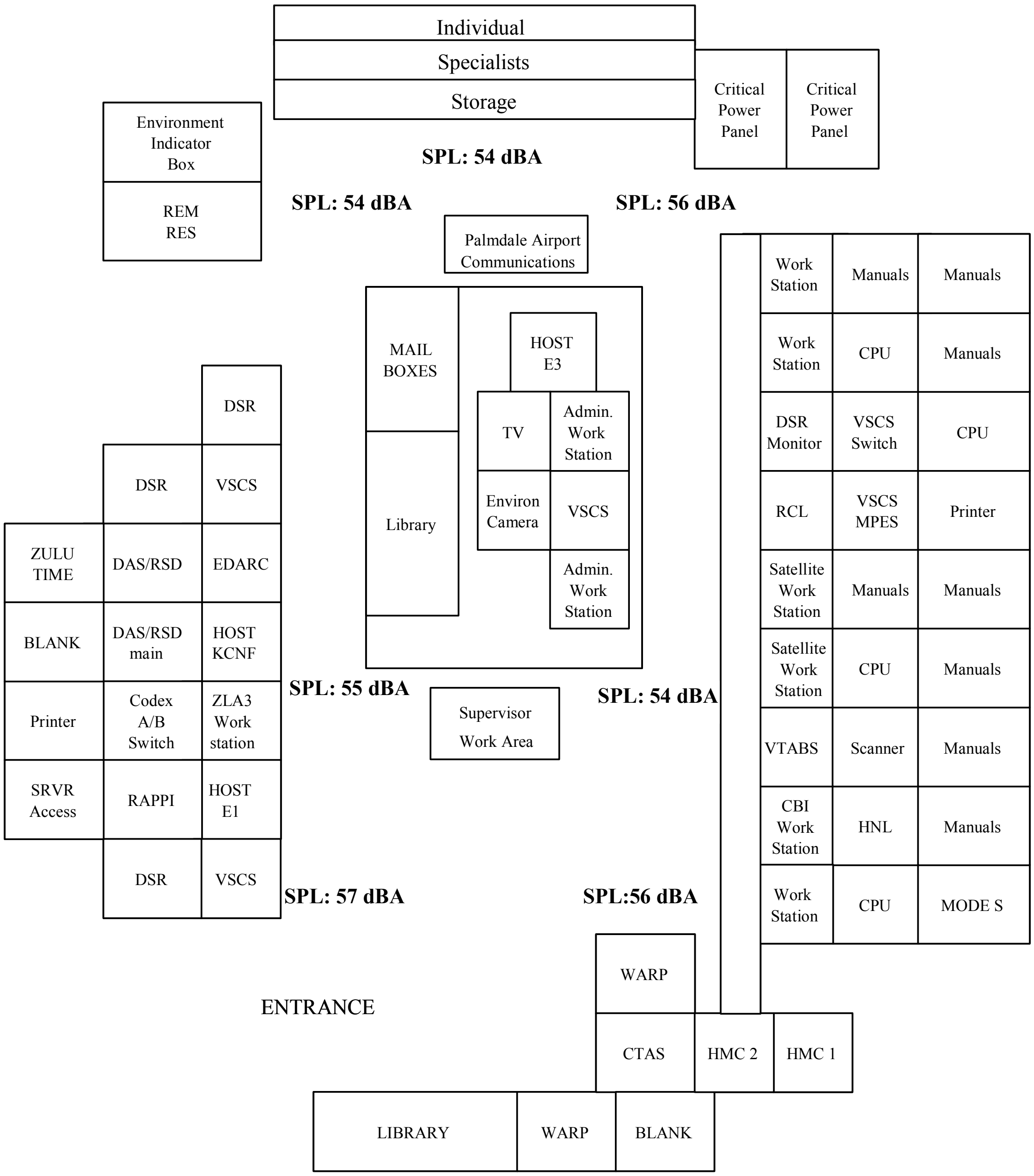
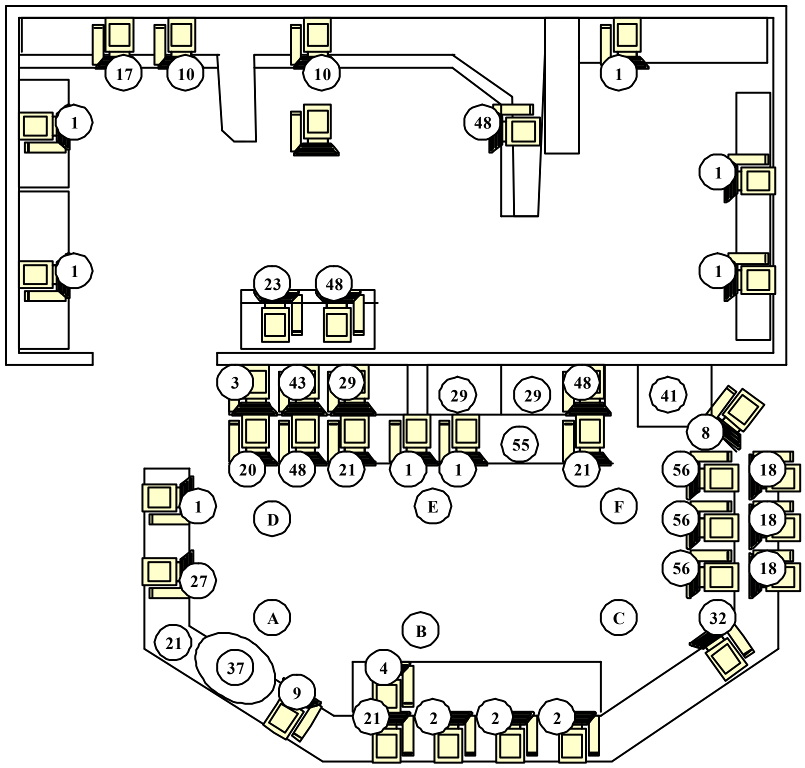


Figure 4. San Diego (Palmdale) ARTCC.



1 – Admin Workstation
2 – ARTS
3 – Codex
4 – CTAS
8 – DVRS
9 – ETMS
10 – EM
17 – MASS
18 – Mode-S
20 – RCL
21 – RDVS
23 – VORTAC
27 – WARP
29 – Environment
37 – BRITE Radar Presentation
41 – ASR-9 System Control
48 – Maintenance Processor Subsystem (MPS)
55 – Touch Entry Device (TED)
56 – Radar Monitor

Ambient sound pressure levels

A = 60 dBA
B = 62 dBA
C = 61 dBA
D = 56 dBA
E = 59 dBA
F = 59 dBA

Figure 5. San Diego TRACON.

POCC – San Diego CA

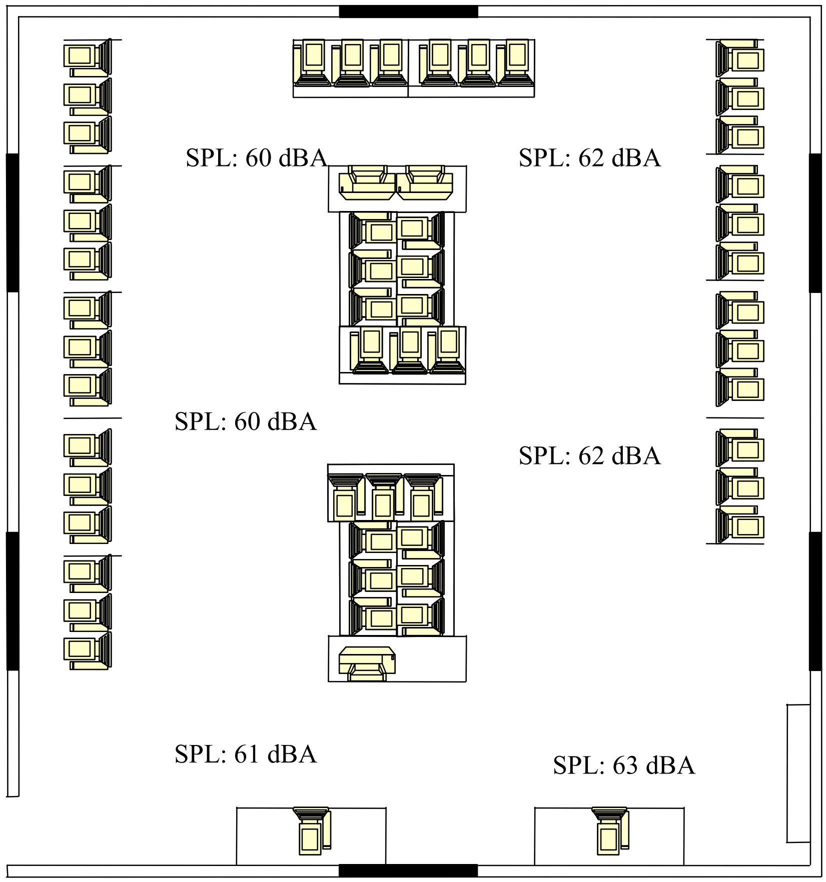


Figure 6. Pacific OCC.

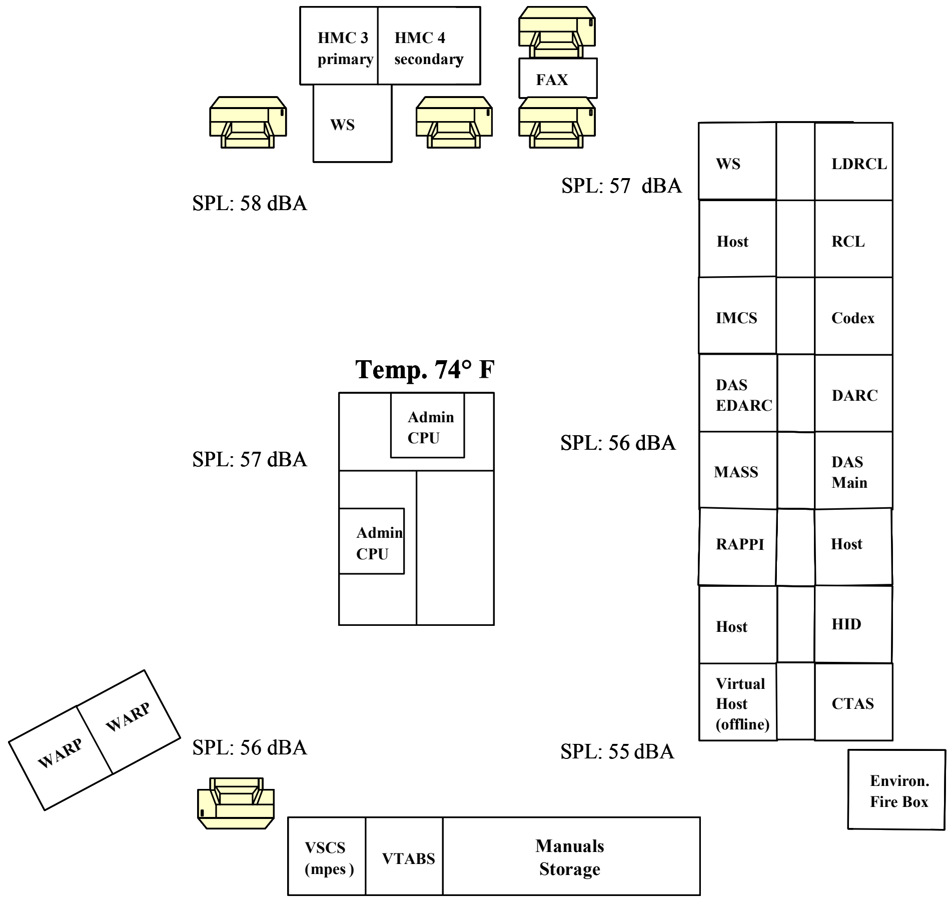


Figure 7. Atlanta ARTCC.

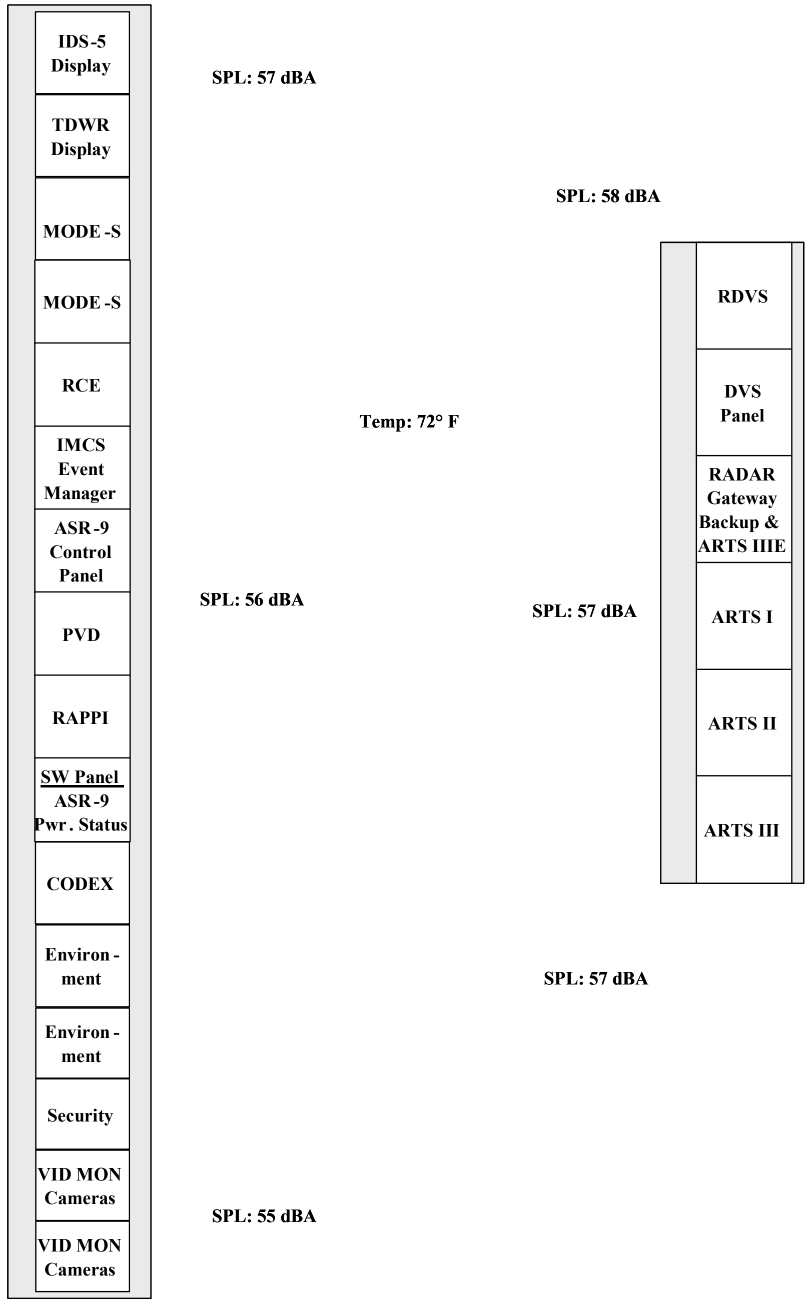
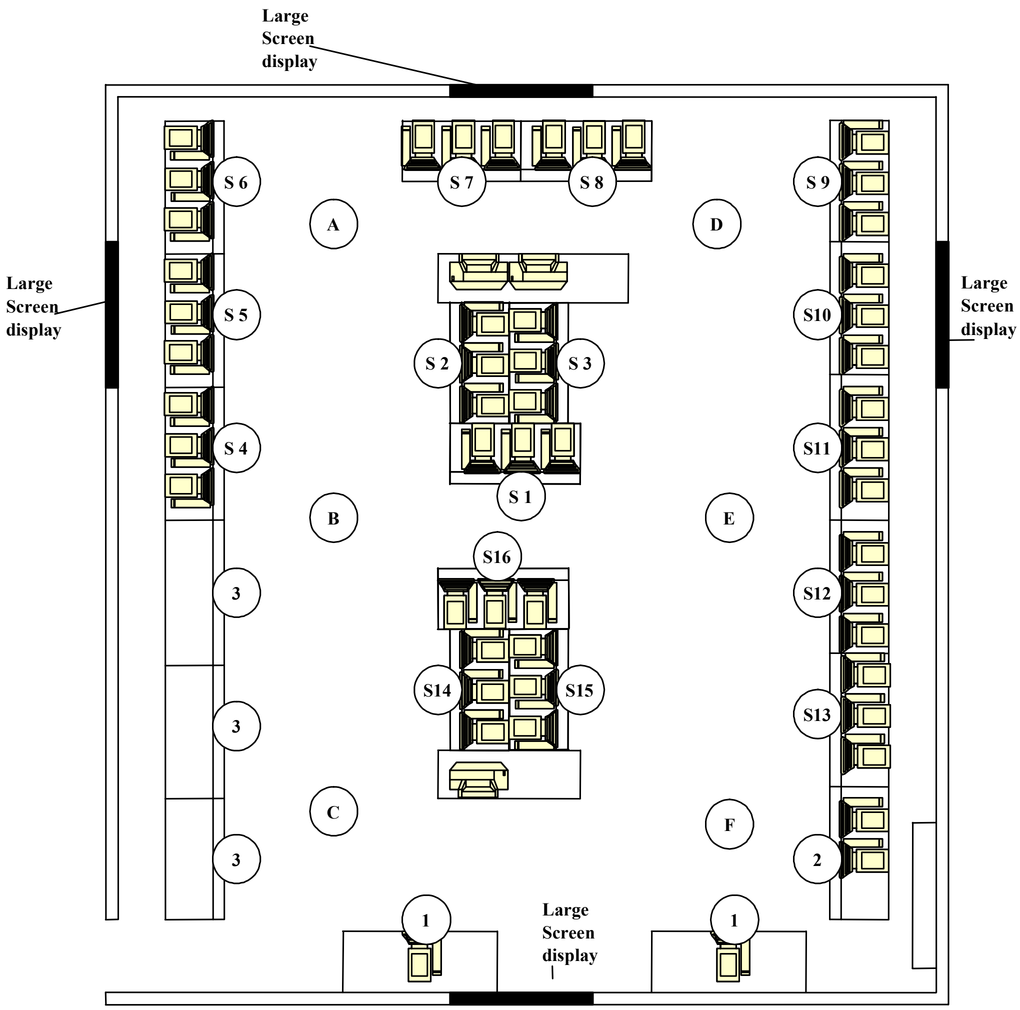


Figure 8. Atlanta TRACON.



1 – Unspecified Workstation
2- NOCC updates
3 – Not set up
S1 – Team leads–MASS, IMCS, EM, Weather, Telephone Software
S2- Team lead MASS, IMCS, EM, Weather, Telephone Software
S3- Team lead MASS, IMCS, EM, Weather, Telephone Software
S4- Nav/Com
S5– Surveillance
S6– Environment
S7 – Nav/Com
S8- Surveillance
S9- Environment
S10- S13- Remote Maintenance Monitoring
S14-S16- Unspecified suites

Ambient sound levels

A = 58dBA
B = 58dBA
C = 58dBA
D = 58dBA
E = 58dBA
F = 57dBA

Figure 9. Atlantic OCC.

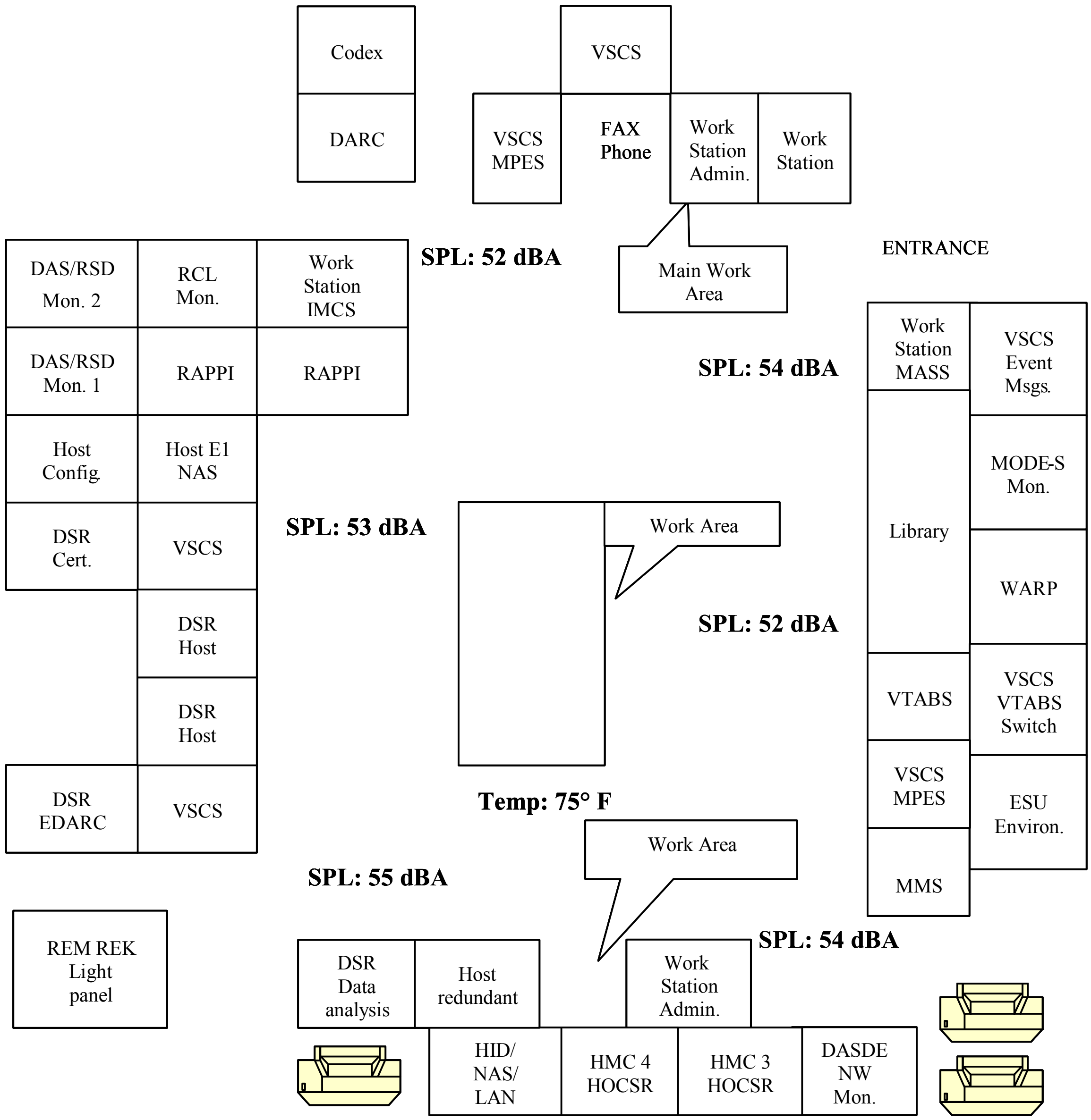


Figure 10. Seattle ARTCC.

In addition to equipment layout, Figures 2 to 10 show the temperature and SPL readings that researchers took at different locations around each site. As the noise level is likely to vary depending on how busy the area is at the time, the researchers obtained estimated workload levels from the participants at the time of each measurement. Even at normal workloads, the ambient environment was fairly quiet, ranging between 52 and 63 dBA (see Table 1). The Human Factors Design Standard (Ahlstrom & Longo, 2003) states that ambient noise in areas requiring frequent telephone use or frequent speech communication at distances up to 1.5 m (5 ft) shall not exceed 65 dBA. Operational areas that require communication at distances of up to 4.6 m (15 ft) shall not exceed 55 dBA. Specialists were within 5 feet of each other for all speech communication observed at the field sites.

Table 1. Ambient Sound Levels at AF Field Sites

Site	**Location A**	**Location B**	**Location C**	**Location D**	**Location E**	**Location F**
Chicago ARTCC SOC	56 dBA	54 dBA	58 dBA	58 dBA	59 dBA	54 dBA
Chicago TRACON SOC	52 dBA	52 dBA	52 dBA	52 dBA	52 dBA	52 dBA
San Diego ARTCC SOC	54 dBA	55 dBA	57 dBA	56 dBA	54 dBA	56 dBA
San Diego TRACON	60 dBA	62 dBA	61 dBA	56 dBA	59 dBA	59 dBA
Pacific OCC	60 dBA	60 dBA	61 dBA	62 dBA	62 dBA	63 dBA
Seattle ARTCC SOC	52 dBA	53 dBA	55 dBA	54 dBA	52 dBA	54 dBA
Atlanta ARTCC SOC	58 dBA	57 dBA	56 dBA	55 dBA	56 dBA	57 dBA
Atlanta TRACON SOC	57 dBA	56 dBA	55 dBA	57 dBA	57 dBA	58 dBA
Atlantic OCC	58 dBA	58 dBA	58 dBA	58 dBA	58 dBA	57 dBA

The ambient SPLs also provide another important piece of information: how to set the intensity of the auditory alarms in that work area. Human factors design criteria states that auditory signals should exceed the ambient noise level by at least 10 dBA (Ahlstrom & Longo, 2003). However, the user should be able to adjust the volume of the audio signal depending on the operational situation and personnel safety (Ahlstrom & Longo). Specialists can use criticality ratings to make decisions on whether turning down the volume of an alarm would impact operations or personnel safety. It is possible that less critical alarms may be turned down with little or no operational impact.

The temperature at the sites visited varied from 72 to 75 degrees Fahrenheit. This was not considered to be a significant enough difference to impact acoustical measurements or sound transmission.

3.2 Alarms Present in the AF Environment

Some of the auditory alarms found at the field sites had already been captured in the auditory alarm database (Ahlstrom & Longo, 2000). Because of the number of alarms at the sites, there were concerns that turning on each alarm for the researcher to measure may annoy specialists and Air Traffic Control Specialists at collocated sites, possibly having a negative impact on operations. Rather than risk impacting operations, researchers did not record or measure the alarms that were already captured in the auditory alarm database. At the sites, researchers recorded alarms and alerts not already contained in the auditory alarm database, then processed and analyzed them through a computer in the audiometric lab at the RDHFL and added them to the database. AF specialists assured the researchers that turning on these alarms for recording purposes would not impact operations. However, there were other alarms for which this was not the case. To avoid the risk of an impact to operations, they did not record these alarms. These alarms are indicated in the tables as "not recorded."

The researchers extracted the frequency and periodicity characteristics of each alarm (see forms in Appendix F). Table 2 provides this information for the ARTCC SOCs. Table 3 provides this information for the OCCs, and Table 4 provides this information for the TRACON SOCs. The researchers also obtained ratings of the criticality and frequency for alarms already in the auditory alarm database from the specialists at the field sites. Researchers measured SPLs for alarms that they were able to activate in the field (see values in Appendix G).

Table 2. ARTCC Alarms

Alarm Name	Predominant Frequency	Periodicity	Criticality	Std Dev	Frequency of occurrence	Std Dev
G3 processor SONA	2950 Hz	Rapidly repeating, single-tone. 100 milliseconds (ms) of alarm followed by 70 ms of silence.	4.8	0.4	1.4	0.5
G3 terminal	3200 Hz	Alarm continues until acknowledged.	3.7	1.1	3.1	1.2
G3 printer beep	3240 Hz	Repeating, single-tone. 250 ms of alarm followed by 150 ms of silence.	2.3	1.3	2.3	0.8
G3 processor power	2870 Hz	Continuous, single-tone.	4.6	0.8	1.2	0.4
DARC SONA	2700 Hz	Continuous, single-tone.	5.0	0.0	1.0	0.0
DAS-RSD coded time source (CTS) alarm	Composite	Voice alarm.	4.1	0.2	2.4	0.9
DAS-RSD enhanced direct access radar channel (EDARC) alarm	Composite	Voice alarm.	2.4	0.9	1.9	0.8
DAS-RSD environmental control systems (ECS) alarm	Composite	Voice alarm.	3.3	1.0	3.2	0.7
DAS-RSD flight service data processing system (FSDPS) alarm	Composite	Voice alarm.	3.0	1.1	2.1	1.1
DAS-RSD halon alarm	Composite	Voice alarm.	2.1	1.0	2.2	1.3

Alarm Name	Predominant Frequency	Periodicity	Criticality	Std Dev	Frequency of occurrence	Std Dev
DAS-RSD high capacity voice recording (HCVR) alarm	Composite	Voice alarm.	3.9	1.6	1.9	0.9
DAS-RSD host alarm	Composite	Voice alarm.	2.6	0.7	2.1	0.8
DAS-RSD national airspace data interchange network (NADIN) alarm	Composite	Voice alarm.	4.5	1.0	2.1	0.8
DCCR alarm	4300 Hz	Repeating, single-tone, sinusoidal. 100 ms of alarm followed by 900 ms of silence.	2.7	0.7	1.9	0.0
DSR Keyboard error alarm	700 Hz	Single-tone alarm	3.0	1.0	2.0	0.8
DSR M&C-E Alarm	3000 Hz	Rapid beep. Rapidly repeating high-frequency beep: 100 ms of alarm followed by 50 ms of silence followed by the alarm again.	1.5	1.1	1.0	0.9
DSR M&C-H and M&C-CH continuous alarm	1400 Hz	Repeating, double beep alarm: 200 ms seconds of alarm followed by 100 ms of silence and 200 ms seconds of alarm again, then 300 ms silence, then repeat.	2.1	0.9	3.3	0.9
DSR Printer alarm	6220 Hz	High-pitched beep, repeats until paper is loaded.	3.0	0.7	2.8	1.0
High capacity voice recorder alarm	2800 Hz	Continuous, single-tone.	3.3	0.8	2.7	1.2
NADIN I Concentrator alarm	3020 Hz	Repeating, single-tone alarm: 200 ms of alarm followed by 200 ms of silence.	1.7	0.7	2.0	0.5
VSCS AC power cutoff switch (both tones)	Composite	Continuous, 2-tone alarm.	1.8	1.2	1.8	0.7
VSCS class 1 alarm	985 Hz, 2950 Hz	Alternating 2-tone alarm, where the lower frequency is followed by a higher frequency tone.	1.8	1.3	2.2	0.8
VSCS class 2 alarm	1980 Hz	Single-tone, continuous high frequency alarm with a reverberating quality.	1.8	1.4	1.8	0.8
VSCS computer chirp	Composite	Continuous, 2-tone alarm.	1.6	1.0	2.0	1.1
VTAB class 1 alarm	Composite	Repeating, multi-tonal alarm. 200 ms of multi-tonal alarm followed by 100 ms of silence.	1.8	1.3	1.8	0.8
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.	1.6	1.2	1.3	0.8
VTAB class 3 alarm	755 Hz, 3090 Hz	Continuous, single-tone.	3.1	1.3	1.6	0.8
CTAS alarm	Between 700-1000Hz	Sounds like dripping faucet, 80.ms of tone followed by 3 seconds of silence.	Not rated		Not rated	
Fire alarm	3382 Hz	500 ms beep followed by 500 ms silence, repeating.	Not rated		Not rated	
Mode-S alarm			Not rated		Not rated	

Alarm Name	Predominant Frequency	Periodicity	Criticality	Std Dev	Frequency of occurrence	Std Dev
DASD alarm	2500 Hz	100 ms beep followed by 90 ms silence, repeating.	Not rated		Not rated	
UPS battery alarm		Not recorded.	Not rated		Not rated	
Fire alarms		Not recorded.	Not rated		Not rated	
Comeo Rider 30 alarm		Not recorded.	Not rated		Not rated	
Auto detect Keyboard Video Display Terminal (KVDT)		Not recorded.	Not rated		Not rated	
Multiprogramming Diagnostic Monitor (MDM)		Not recorded.	Not rated		Not rated	
Johnson Control (ESV)		Not recorded.	Not rated		Not rated	
ARTCC Critical Energy and Power Systems (ACEPS)		Not recorded - reported has same sound as the microwave oven.	Not rated		Not rated	

Table 3. Alarms at the OCC

Alarm	Predominant Frequency	Description	Criticality	Frequency of occurrence
Maintenance Automation Software System (MASS)	Not recorded	Alarms were permanently disabled	Specialists said that the alarms varied in criticality - they said the alarms were not prioritized.	Not rated, but comments indicated they occurred very frequently prior to being disabled.

Table 4. TRACON Alarms

Alarm Name	Predominant Frequency	Periodicity	Criticality	Std Dev	Frequency of occurrence	Std Dev
Automated Radar Terminal System (ARTS) IIIE conflict alert	2800 Hz	Rapidly repeating, single-tone. 250 ms of alarm followed by 30 ms of silence.	5.0	0	2.0	0
ARTS IIIE minimum safe altitude alert	2800 Hz	Repeating, single-tone. 250 ms of alarm followed by 30 ms of silence.	5.0	0	2.0	0
ARTS IIIE Scatter	2730 Hz	Repeating, single-tone. 140 ms of alarm followed by 90 ms of silence.	5.0	0	2.2	0.4
ARTSIIIA minimum safe altitude warning	1360 Hz	Rapidly repeating, single-tone. Identical alarm as the conflict alert.90 ms of alarm followed by 80 ms of silence.	5.0	0	2.0	0
ASR 9 SCIP	2800 Hz	Continuous, high-pitched single-tone.	4.3	0.8	4.0	0.0
Digital voice recording switch – remote	3100 Hz	Continuous, high-pitched, single-tone.	3.2	0.4	2.1	0.4
ICSS computer alarm signal	900 Hz	Repeating, single-tone beep. 200 ms of alarm followed by 200 ms of silence.	3.3	0.6	2.7	0.5
ICSS fuses SONA	2800 Hz	Rapidly repeating, single-tone beep. 100 ms of alarm followed by 70 ms of silence.	3.5	0.7	3.0	0.0
LLWAS alarm	610 Hz	Rapidly repeating triple-beep	4.0	0	1.5	0.7

Alarm Name	Predominant Frequency	Periodicity	Criticality	Std Dev	Frequency of occurrence	Std Dev
		alarm: 70 ms of alarm, 50 ms of silence, 50 ms of alarm, 50 ms of silence, 50 ms, 30 ms of fade-out, 250 ms of silence. The sequence repeats.				
Mode S computer alarm	2190 Hz	Repeating, single-tone.	4.2	0.8	3.0	0
Multi-channel voice recorder alarm	2395 Hz	Rapidly repeating single tone beep. 200 ms of alarm followed by 250 ms of silence.	4.0	0	3.0	0
Rapid deployment voice switch alarm	3200 Hz	Continuous tone with a secondary repeating lower frequency tone.	4.0	0	3.0	0
Rapid deployment voice switch computer	2000 Hz	Repeating, single-tone beep. 50 ms of alarm followed by 1 second of silence.	4.0	0	3.3	1.2
FOTS	800 Hz tone then voice	4 bells, 800 ms each, separated by 150ms, 380 ms pause then followed by a female voice stating "[Location] Fiber Optic Equipment alarm."	Not rated		Not rated	
ILS Panel alarm	50Hz	685 ms beep, 500 inter stimulus interval, repeating (disabled).	Not rated		Not rated	
Mark 20 ILS alarm	50 Hz	Continuous tone	Not rated		Not rated	
Environmental TRACON	1937	Continuous tone	Not rated		Not rated	
ASR-9 power alarm	2900Hz/ 55Hz	Two alternating tones, 580 ms of 2900 Hz alternating with 600 ms of 55 Hz.	Not rated		Not rated	
Customized ARTS alarms		A local programmer at one facility customized ARTS alarms including a police siren sound if the system goes down and a voice stating "I am back" when the system was back on line.	Not rated		Not rated	
DRPDS (power) monitor		Not recorded.	Not rated		Not rated	
FATS		Not recorded.	Not rated		Not rated	
MASS		Not recorded .	Not rated		Not rated	

Ideally, an alarm should convey to the listener information about the criticality (urgency) of the situation indicated by the alarm. In the research literature, this is often referred to as urgency mapping. One characteristic associated with perceived urgency is the interpulse interval. A shorter interpulse interval is associated with increased perceived urgency (Haas & Casali, 1995). As criticality levels (shown in black) increase, interpulse intervals (white) would be expected to increase as well. To be consistent with the recommendations from the literature, an inverse relationship should exist between the criticality and interpulse interval. As seen in Figure 11, this is not the case.

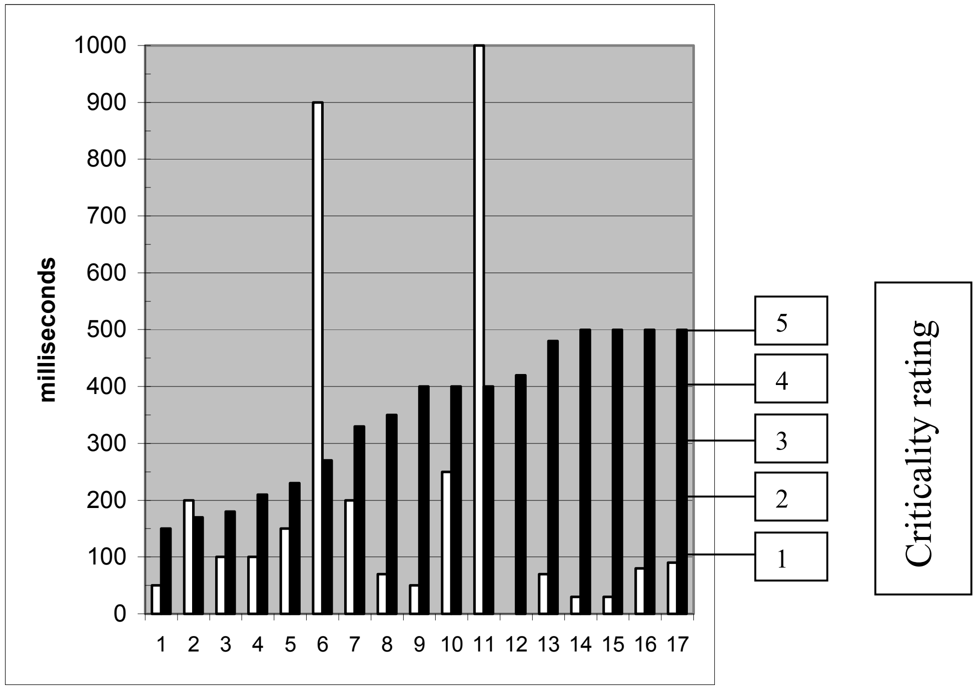


Figure 11. Criticality (black) ratings plotted against interpulse interval (white).

3.3 Ratings Data

The researchers asked the participants to rate 15 different potential issues related to auditory alarms extracted from the auditory alarm literature based on areas that Ahlstrom (2003) identified as problematic in other high workload environments.

The participants rated these questions on how problematic each particular issue was for them at their facility from 0 (not a problem) to 9 (severe problem) based on the severity for each problem. The top five issues for each area are highlighted (see Table 6).

The ranking of the problems was different for the ARTCC and TRACON, although there was some overlap in the top-five ranked items. Although the subject group for the TRACON was relatively small, the ratings were consistent, and there was high correlation within facilities.

3.3.1 Alarms are Easily Confused

As is evident from the ranking of the problems in Table 5, the primary concern found for AF personnel at the ARTCC was that the alarms could be easily confused because they sound alike. This was also a major concern for AF specialists in the TRACON, who ranked it as the number two concern. Alarms that are too similar in frequency or periodicity can be difficult for the user to discriminate (Edworthy, 1994).

Table 5. Ranking at ARTCCS and TRACONS Based on Ratings Data

Auditory Alarm Issues	Rank	
	ARTCC	TRACON
Too many alarms go off at the same time.	3	9
There are too many alarms for a person to learn the meaning of each alarm.	5	7
Alarms sound more urgent than they should or sound less urgent than they should.	11	11
Alarms are easily confused (because they sound alike).	1	2
Alarms can be masked (difficult to hear over the background noise).	4	3
Alarms are too loud.	7	9
Alarms are annoying.	10	11
Alarms disrupt thought.	12	15
Alarms startle the user.	15	6
Alarms interfere with voice communications.	8	13
Alarms go off too frequently, especially false alarms.	9	4
Alarms go off so infrequently that when they do go off, one doesn't know the meaning.	13	13
There are not audio alarms in some situations where there should be audio alarms.	6	1
It is difficult to locate the source of alarms.	14	5
Some alarms that are visual would be better auditory, or vice versa.	2	8

3.3.2 Alarms Can be Masked

Another concern for both the TRACON and ARTCC (ranked number 3 and 4, respectively) was that the noise of the background environment easily masked the alarms. There are two major ways that the environment can mask the alarms. One is through the positioning of the alarms. If the alarms are positioned at a distance from the specialists or if equipment or walls are between the specialist and the alarm, alarms can be masked, particularly if they are higher frequency alarms. The equipment in the ARTCC is laid out over a large area, increasing the possibility of alarms being masked and not heard. The other way alarms can be masked is through similarities between the alarm and the background noise in key characteristics such as frequency. To resolve this issue, it is important to know what types of noise are present in the current environment. In the current environment, there are equipment noises, telephones, and voice as part of the background noise. 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 specialist remarked during the structured interviews that as he got older, it became increasingly difficult to differentiate alarm sounds.

3.3.3 No Audio Alarms Where There Should Be

Personnel at the TRACONs found this issue the biggest concern and ranked it number 1. The TRACON AF work area is collocated with Air Traffic Control Specialists; therefore, there were fewer alarms in AF work areas in TRACONs. AF specialists stated that there were numerous situations where there should be an auditory alarm available to alert the specialists to conditions that required their attention. For example, some personnel suggested the systems such as ASDE, and FOTS that do not have audible alarms but do have critical situations that would need immediate attention should have audible alarms. However, caution should be exercised in adding auditory alarms to the TRACON area as there are already multiple alarms in the area and it is collocated with AT.

3.3.4 Some Visual Alarms Would be Better Auditory or Vice Versa

This was a concern among specialists at the ARTCC. They expressed concern that there were many instances that had only visual alerts with no auditory alarms, such as KVDT alarms for some situations. They said that auditory alarms would be a better choice for more critical situations, whereas for less critical situations an auditory alarm may be unnecessary and a visual alert would be enough to deal with the situation. This was not as significant a concern to the specialists at the TRACON, who ranked it as number 8 out of 15.

3.3.5 There are too Many Alarms to Learn

ARTCC specialists, in particular, were concerned that there are too many alarms. There are over 20 alarms in the AF area of the ARTCC. Human factors guidelines recommend that the number of alarm signals not exceed 12 when relative discrimination is required (Ahlstrom & Longo, 2003). Although people can learn up to six alarms quickly, additional alarms will slow learning and cause confusion (Merideth & Edworthy, 1994; Patterson & Milroy, 1980).

3.3.6 Alarms Go Off too Frequently

A major concern ranked number 4 by the TRACON was the issue of false alarms. Specialists stated that the Instrument Landing System (ILS) alarms in particular tended to produce false alarms. Respondents to this category grouped nuisance alarms with false alarms, stating that some alarms frequently sound for systems or equipment for which AF personnel are not responsible or concerned. Specialists stated that false alarms and nuisance alarms were an obstruction to task performance and often startled the personnel in the area.

3.3.7 Simultaneous Alarms

Another issue identified as a problem area in the ARTCC is multiple alarms going off at the same time. Although this happened mostly during Preventive Maintenance (PM), there were instances otherwise. Too many alarms sounding simultaneously can cause confusion or masking of the alarms. The extent of the masking that occurs depends on how close the alarms are in spectral characteristics, relative loudness, duration, and timing of the sound components. Intermittent signals are less likely than continuous signals to mask other alarms.

3.3.8 Locating the Source of Alarms

Localization of an alarm can be helpful in determining to what an alarm refers and where to direct attention. TRACON personnel said that it was difficult to localize the source of alarms. Several factors, including the spatial location of the sound sources, echoes, and reflections of sound off of equipment and the acoustical characteristics of the sounds themselves, can impact localization. Multiple echoes and sound reverberations from surfaces in the room can make sound localization difficult. The auditory system often compensates by suppressing the late arriving waves from the echoes (Kantowitz & Sorkin, 1983). Sound sources need to be physically separated in order to use auditory localization as an aid.

Alarms that are in the mid frequencies (2000-4000 Hz) tend to be more difficult to localize (Sanders & McCormick, 1993; Stevens & Newman, 1934). This is because higher frequencies are shadowed by the head, causing interaural intensity differences (See Figure 1 on sound shadows). These interaural intensity differences are used to localize the source of the alarms. The interaural intensity differences disappear around 1000 Hz. Interaural time differences are critical to localization for frequencies below 1000 Hz.

The location of the alarm in relation to the user can impact localization. Alarms that are directly in front or in back of the user's head are more difficult to localize as phase shifts are difficult to resolve (Sanders & McCormick, 1993). 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 confusions.

3.4 Structured Interview Results

The overall results of the structured interview questions largely mirrored and expanded upon the results of the ratings data. The analysis reports a summary of issues derived from the answers to the structured interviews.

Overall, specialists felt that auditory alarms were there for a purpose, and it was necessary to have them. However, there were some recurring issues that they identified in the structured interviews.

3.4.1 Acknowledging Alarms

One of the biggest concerns with auditory alarms, centers around the alarms being difficult to acknowledge. Although specialists could turn off or acknowledge most alarms, it was not standard across systems, causing additional cognitive workload for the specialists. Users acknowledge the alarms and then deal with the situation. They would prefer that alarms have a simple way to be acknowledged that silences the auditory portion of the alarm at least temporarily.

Specialists specifically mentioned the Keyboard Video Display Terminal (KVDT) as difficult to acknowledge. They said that it "needs a command to get rid of it and interferes with decision-making about the situation."

3.4.2 Nuisance Alarms

Auditory alarms that sound but do not require specialist attention really bother the specialists. For example, some systems present alarms for non-critical situations and conditions that do not need the AF personnel to be involved. Some examples are as follows:

- The Display System Replacement (DSR) Tape Drive Alarm occurs often during the day and is not critical. Therefore, it is a nuisance.
- The ILS alarm is intrusive because it goes on all the time, even for runways not in use. It also distracts the controllers and, therefore, is a nuisance alarm.
- The FATs alarm monitors temperature. It goes off when the temperature is on the threshold of changing, although the specialist requires no action. It goes on and off continuously because a thermostat adjusts temperature.
- The Maintenance Automation Software System (MASS) alarms have too many non-critical scenarios that cause alarms. Therefore, specialists prefer to turn them off and keep watching the screen and hope to find what is causing the alarm.

3.4.3 Multiple Alarms

The specialists reported that there were very few situations that instigate multiple alarms. Because these situations were rare, they were not of high concern. Situations common to the ARTCC and the TRACON that could generate multiple alarms are a total power failure and PM. During PM, the personnel are aware of the alarms that will sound in advance and can prepare themselves accordingly. A total power failure is a rare event because there are two back up systems. The personnel reported that although there is not a set strategy involved in dealing with multiple alarms, there was a certain bit of decision making involved in acknowledging the alarm and investigating the problem. The common strategy was to gather information and then prioritize the acknowledgment. An alarm concerned with the Host was usually the prime concern. Although multiple alarms were not common, there were some alarms that did tend to occur together. Some of these scenarios are as follows:

- Radar Auto-detect and DSR alarms go off together (very rare).
- When the radar goes down, the processor alarm and the DSR Multiprogramming Diagnostic Monitor (MDM) alarm also goes off. This happens about once a month. The specialists said that it was good to have both the alarms for the same event because having both increases the chances of detection.
- During PM, the Host, DSR, KVDT, and Direct Access Radar Channel (DARC) alarms go off. This happens about twice a week.
- Sometimes DARC alarms occur with the Data Acquisition System Real Time Status Display (DAS/RSD) and DSR. This happens once every 2-4 months.
- The Host and Center TRACON Automation System (CTAS) can alarm at the same time. This happens about twice a month.

- It is possible for radar to fail, which will cause DARC and Mode-S to go off at the same time. This happens less than once a month.
- Weather can cause multiple alarms. It causes multiple ILS failings and FATS alarms.

3.4.4 Alarm Effectiveness

The specialists said that they learned the meanings of the auditory alarms over time, primarily through on-the-job-training. This means that there is a high risk of confusion for specialists who have fewer years of experience. Some specialists said that there were no alarms that were ineffective because, over time, they learned all of the auditory alarms that were important to their job. One of the prime concerns with the alarm design was that most alarms did not tell what action specialists should take. Perhaps this is why many of the specialists reported preferring talking alarms to the tones. Specialists also reported that the voice alarms were less likely to be masked by equipment noise. One respondent mentioned that as he got older, the tones became increasingly difficult to differentiate.

Several respondents said that the DAS RSD, Host, and CTAS alarms were effective because of their uniqueness. The DAS/RSD and Host alarms are voice alarms, and the CTAS alarm sounded like a drip of water.

Some representative comments follow:

- DAS alarms: “I like the way they talk to me and show the report.”
- “CTAS is peculiar and very effective.”
- “Talking alarms are particularly effective.”
- “Voice alarms would be better; tones can be irritating for more of us and for the controllers.”

3.4.5 Testing Alarms

When the research team conducted site visits, they asked the specialists to set off the auditory alarms, where possible, so that they could be captured on audiotape. The specialists reported that they were unable to test some of the alarms. Without testing, specialists had no way to know whether the alarms were functioning properly. Some of the alarms that they mentioned in particular were Digital Voice Recording System, DSR, Voice Switching and Control System (VSCS), VSCS Training and Backup Switch, and Airport Surveillance Radar (ASR)-9. Although specialists could turn off or acknowledge most alarms, it was not standard across systems, causing additional cognitive workload.

3.4.6 Audible Alarms Needed

Some specialists indicated that some systems need audible alarms. Particular systems mentioned were Random Access Plan Position Indicator, ASR-9, Automated Surface Detection Equipment, and Mode-S.

3.4.7 Improving Alarm Signals, Systems, or Responses

There were a few suggestions made to improve the general capabilities of the alarms, improve situation awareness, and assist the personnel in resolving the issues with the systems.

Integrated Monitoring: The personnel from both TRACONs and ARTCCs suggested integrating various systems to provide a central workstation where systems could be monitored together. This would provide a single alarm on the station and offer visual clues to the problem. The current layout of systems on the floor requires specialists to continuously monitor all the screens, and this could cause missing some of the alarms or alerts. In the TRACON, the panels are spread out. Participants suggested a single workstation having the capability to silence all the alarms. The alarms in the TRACON were audible to the controllers also; therefore, they needed to silence them as soon as possible. An integrated system, however, must not be a single point of failure.

Provide an easy way to acknowledge auditory alarms: Personnel from both TRACONs and ARTCCs indicated the need for a simple and standardized way to acknowledge the auditory portion of alarms.

3.4.8 Prioritization of Alarms

Specialists mentioned MASS specifically as an example of a system that could benefit from prioritization of alarms. Additionally, DARC does not differentiate between critical and non-critical alarms.

Voice Alarms (ARTCC-specific). Specialists reported that voice alarms provided a better understanding of the problem; therefore, most of the personnel preferred them. They made suggestions such as we want "an alarm that will spell out the problem to you." A few personnel, who have worked the area for a long time and have completely learned what the tone alarms meant, said that they were more comfortable with alarms as they are in the current systems.

4. CONCLUSIONS/ RECOMMENDATIONS

In order to provide recommendations to both the ratings data and the structured interview data, the major issues from the ratings data and the structured interview questions were combined into 13 major categories. Recommendations on how to address these issues follow each category.

4.1 Alarms Are Easily Confused (Because They Sound Alike)

Recommendation: Alerting and warning systems should be designed to be unambiguous, with a clear indication of the cause for the alert (Ahlstrom & Longo, 2003). This can be accomplished by varying frequency, modulation, or both. Alarms should be separated by at least 400 Hertz in frequency (Newman & Allendoerfer, 2000). Although people can discriminate frequencies closer than this in a laboratory, the operational environment is more acoustically complex than a laboratory. Alarms should also differ in periodicity, taking care to avoid continuous signals (Ahlstrom & Longo). 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 (Merideth & Edworthy, 1994).

4.2 Alarms Can be Masked (Difficult to Hear Over the Background Noise)

Recommendation: Alarms should be different enough in frequency and periodicity from environmental and background noises (including phone sounds and people talking) that they can be easily discriminated. The intensity, duration, and source location of audible alarms should be compatible with the acoustical environment of the intended receiver (Ahlstrom & Longo, 2003). AF environments typically have equipment noises, the ring of telephones, and voices. Additionally, alarms in the AF environment are subject to the physical layout of the objects and equipment within that environment. Objects in the environment can significantly impact the absorption and reflectance of an alarm sound, depending on the characteristics of the alarm and the materials present in the environment. The presence of more sound absorbing material can reduce the overall SPL and the SPL of reflected sounds. 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 (Nanthavanij, 1995). Masking can be influenced by similarity to the frequency and periodicity of background noises and by intensity. Designers should ensure that the characteristics of the alarm sounds are sufficiently different so as not to be confused with sounds present in the environment, such as equipment sounds or phones ringing (Ahlstrom & Longo).

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 alarms. In order for an alarm not to be masked by the background noise, it must be placed at a location where the intended user can optimally perceive it (Nanthavanij, 1995). One way to ensure operational suitability is to test and evaluate alarms for usability and user acceptance. Researchers should place representative users in as near to a realistic operational environment as possible before the signals are incorporated into a system (Ahlstrom & Longo, 2003).

4.3 Appropriate Use of Audio and Visual Alerts

Recommendation: Provide auditory alarms where needed to provide a better probability of detecting malfunctions or conditions that may cause injury or equipment damage (Ahlstrom & Longo, 2003). An audio signal should be provided when any of the following conditions apply:

- 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 (Ahlstrom & Longo).

4.4 There Are Too Many Alarms for a Person to Learn the Meaning of Each Alarm.

Recommendation: Ensure that the number of audible alarms in an environment is consistent with the abilities of the end user. Research shows that people can learn between four and seven alarms reasonably quickly; however, performance decreases dramatically with additional alarms. Because four is the lower limit when absolute identification (the user is required to identify the alarm based on the auditory portion alone) is required, the number of signals that the user can identify should not exceed four. Up to nine alarm signals can be used if they are presented on a regular basis because users can retain the meanings associated with up to nine alarms if the alarms are presented regularly (Ahlstrom & Longo, 2003; Patterson, 1982; Stanton & Edworthy, 1994). When relative discrimination is required instead of absolute identification, the number of alarm signals can be expanded up to 12 (Stanton & Edworthy).

Efforts should be made to minimize the number of alarms that specialists are required to discriminate. Auditory alarms should only be used when they contribute to the understanding of and appropriate responses to an event. Human factors guidelines recommend that the number of alarm signals not exceed 12 in an environment when relative discrimination is required (Ahlstrom & Longo, 2003). When adding new alarms to an environment, designers should consider the number of alarms that already exist. One means of increasing the number of signals that can be identified is by increasing the number of dimensions used in coding sounds (Deathridge, 1972). When several different audio signals will be used to alert the user to different conditions, the signals should be different in intensity, pitch, or use of beats and harmonics (Ahlstrom & Longo, 2003). If the new alarms are tone alarms, the alarms should vary significantly in intensity and frequency to increase the discrimination of the alarms. Designers should consider voice alarms, where appropriate. Voice alarms 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 does not preclude verbal communication among specialists (National Research Council, 1997).

4.5 Alarms Go Off Too Frequently, Especially False Alarms

Recommendation: Determining whether an alarm is irrelevant or requires action by an AF specialist can take time from other important tasks and can increase workload. Systems that cause frequent false alarms should be evaluated, and a concerted effort should be made to reduce the number of irrelevant alarms.

4.6 Nuisance Alarms

Recommendation: Alarms that sound for conditions that do not require user attention often cause annoyance to the users and can distract the users from performing their primary tasks (Ahlstrom, 2003). Auditory alarms should not be present in the operational environment if they do not provide meaningful information to the intended user. Designers should take steps to minimize nuisance alarms.

4.7 Too Many Alarms Go Off at the Same Time – Multiple Alarms

Recommendation: Although only one system in the OCCs had auditory alarms, it was ironic that the alarms on that system were disabled. The justification for disabling the alarms in this environment was that they lacked a prioritization scheme. Therefore, multiple alarms would sound simultaneously, causing annoyance for the user. Many of the alarms did not provide useful information to the listener, thus defeating the purpose of having auditory alarms.

Researchers recommend prioritizing alarm situations based on action required of the specialists. Multiple alarms sounding simultaneously could interfere with the decision making of the operator or could mask other critical warning signals (Ahlstrom & Longo, 2003). By design, auditory alarms must not result in user confusion, errors, or inefficiencies in response (Ahlstrom & Longo). This means that designers must take an integrated approach to alarm design, taking into account relationships between systems and priorities to users. Alarms should be automatically organized and presented to the users in prioritized form, with the most significant alarms receiving the highest priority (Ahlstrom & Longo). Because systems are often interconnected in the AF environment, multiple alarms could be generated from a single failure. When two or more incidents or malfunctions occur simultaneously, the one with the higher priority should be presented first (Ahlstrom & Longo). It may be necessary to identify the fact that multiple alarms are in the queue, if warranted by the situation.

In the event of a complete system failure, the system could, by design, integrate messages and report the system failure with a single auditory alarm rather than generate auditory alarms for each of the failed components (Ahlstrom & Longo, 2003).

4.8 It is Difficult to Locate the Source of Alarms

Recommendation: Specialists said that alarms are difficult to localize. There are several ways to address this issue. One way is to minimize the need for localization by providing a centralized alarm panel or window indicating the alarm status for most alarms. The AF specialists provided this recommendation. Auditory alarms could be consolidated into a centralized alarm panel or window only if immediate identification of the appropriate visual display is not critical to personnel safety or system performance (Ahlstrom & Longo, 2003).

Another approach is by the location of the alarms. Alarms that are located immediately in front of or behind the head of a specialist can be the most difficult to localize. Another way is through the design of the alarms themselves. Alarms that are in the mid-frequencies (1500-3000 Hz) are the most difficult to localize (Sanders & McCormick, 1993).

In addition, sounds can reverberate from hard surfaces in the environment, creating echoes that further complicate localization. Several strategies can maximize the ability to localize auditory alarms. Alarms can be made with a broad spectrum, avoiding the mid frequencies. Alarms can be located off to the side instead of directly in front or in back of the user. Minimizing hard surfaces or adding sound absorptive material in the environment can decrease echoes (Nanthavanij, 1995).

4.9 Acknowledging Alarms

Recommendation: Provide a simple and standardized means of acknowledging audible alarms. All systems and applications should have a simple, consistent means of acknowledging the audible portion of an alarm that at least temporarily silences the auditory portion of an alarm as specialists address the problem. However, this acknowledgement should not inhibit or slow the response to the condition initiating the alarm (Ahlstrom & Longo, 2003).

We also recommend providing a simple, consistent means for turning off non-critical auditory alarms. This should occur without erasing any displayed message that accompanies the auditory signal once the user has acknowledged the alarm or corrected the condition generating it (Ahlstrom & Longo, 2003). Alternately, the system could include a sensing mechanism that automatically shuts off the auditory portion of the alarm once it no longer provides useful information consistent with the operational situation and personnel safety (Ahlstrom & Longo).

4.10 Alarm Effectiveness

Recommendation: It was clear from the structured interviews that many of the specialists preferred voice alarms, which clarify the alarming condition and subsequent action required of the user. 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 (Ahlstrom & Longo, 2003). When these signals are used, they should consist of a brief speech signal identifying the condition and suggesting appropriate action. As with the tonal signals, these signals should be tested with representative users and evaluated for usability (including detection and identification), operational suitability, and user acceptance. They can accomplish this by placing representative users in as near to a realistic operational environment as possible before the signals are incorporated into a system (Ahlstrom & Longo). If voice signals are used, they should comply with the design criteria provided in the Human Factors Design Standard (Ahlstrom & Longo).

4.11 Testing Alarms

Recommendation: Researchers observed that some of the alarms were not easy for the specialists to test. Human factors guidance recommends that auditory alarms be easy to test and adjust (Ahlstrom & Longo, 2003). The reasoning behind this recommendation is so that the auditory alarm itself does not become a point of failure.

4.12 Learning the Meaning of Alarms

Recommendation: Specialists indicated that, primarily, on-the-job training taught the meanings associated with auditory alarms. Because there is limited time for the specialists to learn these meanings, designers should strive to use alarm signals that are easy for the specialists to learn and remember.

4.13 Integrate the Audible Alarm System Where Appropriate

Recommendation: Specialists expressed a desire for an integrated alarm system that would allow them to view and acknowledge alarms from a centralized location. The potential for an integrated alarm system should be evaluated. The benefits for such a system will minimize localization and masking issues and allow easy acknowledgement of alarms. Specialists were clearly in favor of such an integrated alarm system that would allow them to see the alarm and acknowledge it from a single location. If such an alarm system is used, care should be taken to ensure it is not a single point of failure.

5. FINDINGS

Human factors guidance recommends that auditory signals requiring different user responses be easily distinguishable from one another (Ahlstrom & Longo, 2003). In the terminal environment, the conflict alert and the Minimum Safe Altitude Warning alarms are exactly the same. Although the periodicity (pattern) is different, the two systems have the same base frequency, increasing the probability for confusion. In the en route environment, a power alarm and a high capacity voice recorder alarm are both continuous single tone alarms and only 70 Hz apart in frequency. This increases the probability for confusion. Alarms should be easily distinguishable from one another. Varying frequency and modulation (periodicity) is one way to accomplish this.

Both the en route and terminal environments had alarms with several continuous tones. In general, auditory tones should be intermittent rather than continuous. Continuous tones are more easily confused, even when they vary significantly in pitch. Furthermore, the human auditory system adapts quickly to continuous tones.

The auditory alarms should be compatible with the acoustical environment in which it is located (Ahlstrom & Longo, 2003). Additionally, auditory alarms should be clearly distinguishable from other audible tones such as telephone ring tones used at the AF sites and other environmental noises. Ways to accomplish this include using different frequencies, periodicity, or both.

Researchers identified over 38 different auditory alarms in the AF en route environment and 22 in the terminal environment. Although not all of these alarms may be found at all en route SOC locations, the number of alarms definitely exceeds the 4 recommended for absolute identification and 12 recommended for relative discrimination (Ahlstrom & Longo, 2003). There are several viable strategies that can minimize the number of alarms. One strategy is to examine the alarms that do not require immediate user action. These alarms could be candidates for removal of the auditory portion, or they could be integrated into a consolidated alarm application that shows all of the alarm information and ideally allows the user to access this information from anywhere in the room. Auditory alarms should only be used when they contribute to the understanding of and appropriate responses to the operational and task environment (Ahlstrom & Longo).

The researchers found that there was no clear prioritization scheme associated with the alarms. There was no clear difference in the design between alarms that required immediate user action (those rated as critical by the users) and those that did not. Additionally, there was no automated filtering of alarms based on priority. Thus, alarms that were less critical often sounded at the same time as the more critical alarms. Research has shown that increasing the speed of the beeps relates to increases in perceived urgency of the situation associated with the auditory alarm (Patterson, 1982). Alarms should be automatically organized and prioritized (Ahlstrom & Longo, 2003). When two or more alarms occur simultaneously, the one indicating the higher priority should override the alarms having lower priority. However, the number of priority levels should be limited to four (Ahlstrom & Longo).

The en route environment uses several voice alarms. Voice alarms can be an appropriate solution when there are numerous signals whose meanings could be forgotten. However, care should be taken to ensure that the environment does not mask the voice alarms. Care should also be taken to ensure that the voice alarms do not interfere with the user's ability to address the situation indicated by the alarm. These considerations are particularly important for the AF environment, where many tasks rely on verbal communication. There are many guidelines that provide specific guidance for voice alarms (e.g., presentation, word choice, type of voice) (Ahlstrom & Longo, 2003).

In general, the critical alarms did not occur very frequently. This could cause the specialists to forget the meaning of the alarms. At most of the facilities, however, there were procedures in place that required the personnel to set off the alarms periodically to make sure that they were working. This helped the personnel to remember what the rare alarms sounded like.

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Acronyms

ACEPS	ARTCC Critical Energy and Power Systems
AF	Airway Facilities
ARTCC	Air Route Traffic Control Center
ASR	Airport Surveillance Radar
CTAS	Center TRACON Automation System
DARC	Direct Access Radar Channel
DAS RSD	Data Acquisition System Real time Status Display
DAT	Digital Audio Tape
DOT	Department of Transportation
DSR	Display System Replacement
FAA	Federal Aviation Administration
KVDT	Keyboard Video Display Terminal
ILS	Instrument Landing System
MASS	Maintenance Automation Software System
MDM	Multiprogramming Diagnostic Monitor
NAS	National Airspace System
OCC	Operations Control Center
PM	Preventative Maintenance
RDHFL	Research and Development Human Factors Laboratory
SOC	Service Operation Center
SPL	Sound Pressure Level
TRACON	Terminal Radar Approach Control
VSCS	Voice Switching and Control System
WJHTC	William J. Hughes Technical Center

Appendix A

Description of Study

Alarms and Alerts in Airway Facilities Service Operations Centers and Operations Control Centers

<u>Description for participants</u>

<u>Purpose</u>	To collect information about existing auditory alarm signals and alerts and evaluate them against human factors rules and guidelines in an attempt to create the standards for auditory alarms and alerts at the Airway Facilities.
<u>General Information</u>	• The researchers will first collect data on the alarms (characteristics including frequency, periodicity) and the ambient environment (temperature, pressure and SPL). • The researchers make up the facility layout map to analyze audio data. • The researchers will then interview the participants for about 40 minutes. • The participants will be asked details about the auditory alerts and their characteristics. • The participants will be asked to comment on the general acceptability of the alerts and ways to make them more efficient and acceptable. • The researchers will take notes to document the interview. The interviewees may see or refer to interviewer notes at any time. • The researchers will then analyze the objective data collected and the opinions of the participants documented and recommend ways for standardization of the auditory alarms at the Airway Facilities. • There are no risks or discomforts involved in this research study.
<u>Confidentiality</u>	Participation in this study is strictly voluntary. The confidentiality of participants will be strictly protected. No individual names will be recorded or released in any reports.
<u>Schedule</u>	The researchers will be at each site for a complete day.
<u>Place</u>	The research will take place at the individual facilities.
<u>Contact Person</u>	Vicki Ahlstrom, (609) 485-5643, vicki.ahlstrom@faa.gov Gulshan Panjwani, (609) 485-7764, gulshan.panjwani@titan.com

Appendix B

Informed Consent

ALARMS AND ALERTS IN AIRWAY FACILITIES SERVICE OPERATIONS CENTERS AND OPERATIONS CONTROL CENTERS

Individual's Consent to Voluntary Participation in a Research Project

I understand that this study, entitled "Alarms and Alerts in Airway Facilities Service Operations Centers and Operations Control Centers", is sponsored by the Federal Aviation Administration Office of the Chief Scientific and Technical Advisor for Human Factors (AAR-100) and is being directed by Vicki Ahlstrom.

Nature and Purpose

I have been recruited to volunteer as a participant in the project named above. The purpose of this part of the research is to collect information about existing alarm signals and systems. My role as a participant will be to provide technical information and my perceptions as a subject matter expert about audio alarms and alerts. This information will be obtained through verbal interviews and in written responses to questions based upon my experience. The information will help determine design and operations issues and guidelines for potential improvements in future alarm systems.

Interview Procedure

The interview will take about 30 to 40 minutes. The interviewer will take notes during the interview and I am allowed to refer to the notes at any time during the interview. Audio recordings will also be made to allow researchers to complete their notes after the interview. However, the recorder will not be used if the participant requests it were turned off.

Confidentiality and Anonymity

I understand that records of this study will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this study. My name will not be attached to any information provided in any records. All collected information is for use within the Research and Development Human Factors Laboratory only. Data will be coded using numbers instead of the participant names and no permanent record of the participant names will be maintained

Benefits

I understand that the only direct benefit to me is the satisfaction of knowing that I contributed to our knowledge about the audio alarms and alerts.

Risks

No risks are expected.

I agree to immediately report any injury or suspected adverse effect to my supervisor at the site. I understand that accident insurance coverage for this activity is provided by my own insurance and that necessary immediate care of resultant medical problems may be provided by my facility until, or unless, transportation to another medical facility is obtained. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Participant's Assurances

I understand that my participation in this study is completely voluntary. I am participating because I want to. Any and all questions I have about this study, my participation, and the procedures involve have been answered. I understand that the researcher will be available to answer any questions concerning procedures throughout this study.

I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed that I have not given up any of my legal rights or released any individual or institution from liability for negligence by consenting to this survey. I understand that I can withdraw from the study at any time without penalty or loss of benefits to which I am otherwise entitled. I also understand that the researcher may terminate my participation if he feels this to be in my best interest.

If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Vicki Ahlstrom (609) 485-5643 or Gulshan Panjwani at (609) 485-7764 (gulshan.panjwani@titan.com).

I have read this consent document, understand its contents, and I freely consent to participate in this study under the conditions described.

Research Participant: ____________________________Date: _____________

Investigator: ____________________________________Date: _____________

Witness: _______________________________________Date: _____________

Appendix C

General Problems Associated With Audio Alarms

We are trying to identify areas where audio alarms are a problem. The following is a list of possible problem areas. There may be problems with alarms in your area that are not listed or some that are listed may not be a problem for your area. Please give your comments on what problems you feel exist with auditory alarms in your area. Please rate the severity of each of these issues from 0-10, with 0 meaning not a problem whatsoever to 10 meaning a severe problem which should have immediate attention.

Too many alarms go off at the same time.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
There are too many alarms for a person to learn the meaning of each alarm.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms sound more urgent than they should or sound less urgent than they should.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms are easily confused (because they sound alike).	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms can be masked (difficult to hear over the background noise).	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms are too loud.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms are annoying.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms disrupt thought.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms startle the user.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms interfere with voice communications.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms go off too frequently especially false alarms.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Alarms go off so infrequently that when they do go off, you don't know the meaning.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
There are not audio alarms in some situations where there should be audio alarms.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
It is difficult to locate the source of alarms.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem
Some alarms which are visual would be better auditory or vice versa.	Not a problem 0 1 2 3 4 5 6 7 8 9 10 Severe problem

Appendix D

Structured interview protocol

Explain the purpose of the visit and provide description of the study.

Provide the voluntary consent form.

Provide a list of known alarms associated with different equipment.

Questions:

1. In order to learn more about alarm and alert signals and issues associated with them, we would like for you to look at a list of alarms and circle alarms that you deal with. Please indicate how frequently you deal with each of these alarms and how immediate the user response must be for each alarm.

2. Are there alarms that you know about that are not on this list?

3. Of all the alarms that you know about, which ones are the most intrusive (interfere with thinking, responding, etc)? Why do you feel that they are intrusive?

4. How do people handle intrusive alarms?

5. Are there alarms that are likely to be sounding during the same time period?

6. How often do you experience multiple alarms? Under what circumstances does this occur? How do you handle multiple alarms?

7. Are there alarms that are likely to be missed? Why?

8. Are there alarms that are likely to be disabled? Why?

9. Are there alarms whose intensity is turned down? Why?

10. Are there alarms that are not adjustable, testable, or easy to turn off or down? Are there alarm signals that are particularly effective? What do they sound like? How do you know what alarm it is, and what is particularly good or effective about it?

11. Are there alarms that are particularly ineffective or problematic in some way?

12. Are there alarms that present irrelevant or false information? How are these handled? What do they sound like, how do you know what alarm it is and what is wrong or needed?

13. How could alarm signals, systems, or responses be improved?

14. How did you learn what the alarm signals mean? Is training necessary to learn the meaning of the alarms or how to respond to them?

Appendix E

Environmental Data

Data about the ambient environment will be collected at each field site. Measurements of temperature, barometric pressure, and sound pressure level will be taken at each field site. Prior to data collection, a map or sketch of the layout will be obtained or created. The location and time of measurements along with the results of the measurements will be recorded on the map. If space does not allow, a letter or number will be used to indicate the location and the results will be recorded below.

Location: ____

Time: ____

A Temp_____ SPL______ Pressure______ Taken at:____________	B Temp_____ SPL______ Pressure ______ Taken at:_____________	C Temp_____ SPL______ Pressure ______ Taken at: ____________
D Temp_____ SPL______ Pressure ______ Taken at: ____________	E Temp_____ SPL______ Pressure ______ Taken at: ____________	F Temp_____ SPL______ Pressure ______ Taken at: ____________

Appendix F

Alarm List

Alarm Name	Frequency of occurrence	Immediacy of response
604overheat		
AIDC Alarm		
ARTS IIIA conflict alert		
ARTS IIIE ASR8 SRAP - equipment room		
ARTS IIIE conflict alert		
ARTS IIIE minimum safe altitude alert		
ARTS IIIE Scatter		
ARTSII 7500 aircraft hijack alarm		
ARTSII BRITE remote alarm - equipment room		
ARTSII MSAW-CA		
ARTSIIIA minimum safe altitude warning		
ASR 9 SCIP		
CCCH 3082 processor SONA		
CCCH 3180 terminal		
CCCH 3268 printer beep		
CCCH 3814 processor power		
CDC-DCC IO terminal		
DARC SONA		
DAS-RSD coded time source (CTS) alarm		
DAS-RSD enhanced direct access radar channel (EDARC) alarm		
DAS-RSD environmental control systems (ECS) alarm		

Alarm Name	Frequency of occurrence	Immediacy of response
DAS-RSD flight service data processing system (FSDPS) alarm		
DAS-RSD halon alarm		
DAS-RSD high capacity voice recording (HCVR) alarm		
DAS-RSD host alarm		
DAS-RSD national airspace data interchange network (NADIN) alarm		
DAS-RSD non-radar keyboard multiplexer (NRKM) alarm		
DCCR alarm		
digital voice recording switch - remote		
DSR Keyboard error alarm		
DSR M&C-E Alarm		
DSR M&C-H and M&C-CH continuous alarm		
DSR Printer alarm		
enhanced terminal voice switch		
enhanced terminal voice switch SONA		
high capacity voice recorder alarm		
ICSS computer alarm signal		
ICSS fuses SONA		
ICSS power supply		
ISD Alarm		
LLWAS alarm		
MCS area computer chimes alarm		
MCS area computer chord alarm		

Alarm Name	Frequency of occurrence	Immediacy of response
MCS area computer ding alarm		
MCS area computer tada alarm		
Message Waiting Alarm-D position		
Mode S computer alarm		
multi-channel voice recorder alarm		
NADIN I Back end processor		
NADIN I Concentrator alarm		
OCS IBM Processor Critical Alarm		
OCS IBM Processor Major Alarm		
OCS IBM Processor Minor Alarm		
Odaps 3268 Printer Alarm		
ODL Alarm		
PVD keyboard (version 1)		
PVD keyboard (version 2)		
PVD Overheat		
rapid deployment voice switch alarm		
rapid deployment voice switch computer		
RDVS remote alarm		
remote enhanced terminal voice switch in tower		
remote enhanced terminal voice switch in tower - second alarm		
small tower voice switch alarm		
small tower voice switch power supply unit - 1 alarm		

Alarm Name	Frequency of occurrence	Immediacy of response
small tower voice switch power supply unit - both alarms		
STARS 7500, 7600, 7700 alarm		
STARS CA		
STARS Critical subsystem failure alarm		
STARS Mode C Intruder		
STARS MSAW		
STVS computer alarm signal		
Syscon Line Printer Alarm		
TMS aircraft situation display sector alert (ASD)		
TMS window obscuring update alarm (ASD)		
VSCS AC power cutoff switch (both tones)		
VSCS class 1 alarm		
VSCS class 2 alarm		
VSCS computer chirp		
VTAB class 1 alarm		
VTAB class 2 alarm		
VTAB class 3 alarm		
WMSCR alarm		

Appendix G

SPL Values for New Alarms

Alarm	**SPL Value**
O’Hare fiber optic equipment alarm: 4FOTSalarm	95 dBA
ASR power Alarm	75 dBA
CTAS Alarm	65 dBA
DASD Alarm	75 dBA
Environmental Alarm: Center	80 dBA
Environmental Alarm: TRACON	86 dBA
Fire Alarm: Center	92 dBA
ILS	78 dBA
ILS Alarm: TRACON	71 dBA
Power Alarm: Center	79 dBA