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Audio Environment Design Applied To Long Duration Space Missions

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Audio Environment Design

Applied to Long Duration Space Missions

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Abstract

In future space missions when distances and durations become longer, elements of spacecraft design, previously thought to be irrelevant, will carry extreme importance. Issues that may occur during a long term space mission are identified using research from analogue earth environments; locations on earth which have similar attributes to space, such as extreme climate or confinement. Music and sound research is then applied to these locales to show the positive changes that can result from the use of proper audio design, both in acoustics and generated sounds. Potential solutions are provided, as well as equipment options.

Contents

List of Tables and Figures

Executive Summary

Current space travel is limited to relatively short distances and durations. The crews of these space missions are generally highly trained military personnel, who have become acclimated to high stress situations. When space missions begin covering greater distances or last for longer periods of time, new issues resulting from the traditional design of spacecraft will result.

With the exception of shielding damaging noise from crew members, or providing them with some form of personal media storage, little thought has been given to the design of the audio environment for a spacecraft. The audio environment pertains to the acoustics of individual rooms, the way sound moves and travels; availability of music, how it is transferred to the crew, where it is stored; transmission of audio for communication, or personal use; and noise cancellation, for reducing or eliminating annoying background noises etc..

Since there is not much study in the area of space travel and sound together, research for the subject had to be extrapolated from other fields. Space is characterized as in ICE EUE, an isolate confined environment which is also extreme and unusual. These types of environments also exist on earth in the form of Antarctic bases, submarines, and prisons. All of these locations can be used to show the affect of an environment on crew stress levels, and how sound can be used to combat these issues. (Suedfeld and Mocellin 1987)

When long duration missions become common place and the crews on board become larger and more diverse, the crew will more closely resemble a common office place as opposed to a high tech laboratory. For this reason research from office environments was used. From office environments, as well as music therapy studies, information can be ascertained about topics related to productivity in relation to worker stress. These topics are explored by looking at psychological responses to music and sound.

One topic that was explored was the use of Muzak's patented stimulus progression, the process of classifying pieces of music by their beat and mood and then playing those pieces at predetermined time intervals throughout the day to encourage positive mood. From other studies it was determined that familiar music induced positive mood change, increased productivity, and increased sleep quality. Music that listeners found annoying induced a negative mood change. With this information the conclusion was drawn that crew members be allowed access to a near infinite library of music, where the process of stimulus progression would be applied using musical pieces which the listener has a preference for.

This process only works if all of the music that is heard is considered pleasant by the listener. This means audio propagation must be reduced as much as possible by means of carefully placed construction materials which divert sounds away from quiet areas. This also requires the use of construction materials with a high noise reduction coefficient. In addition to limiting propagation of unwanted noise, specialized speakers can be used to ensure only small areas are targeted for noise saturation. These target sizes can be limited to an individual by means of highly directional speakers, and bone conductivity devices.

Target sizes can also be limited by the use of noise cancelation. This process involves monitoring an audio environment and determining which sounds heard are noise and which are intended to be heard. This can be applied at a crew level by means of a two way communicator, which will have a similar sampling of audio content as the listener who is wearing the device. Speakers can then be used to generate sounds to nullify the offending noise.

It is not enough to simply give every crew member a portable music device, or to ensure that crew cabins are away from noise sources. The audio environment of a spacecraft has to be thoroughly considered not only during the physical design stage but also during the design of ship practices. Sound

will follow the crew of the ship wherever they go. It is imperative that the audio environment promotes a good work environment to ensure not only a successful mission, but a healthy crew.

Introduction

Space missions of the future will last significantly longer than the missions we see today. Even at greater speeds our spacecraft would still take years to reach planets in our own solar system. As we venture further into space we will be manning outposts along the way. These outposts will be inhabited by people for years at a time, and eventually will become permanent homes with many residents. Large outposts, and presumably larger spacecraft, will require large crews to man them. Astronauts are currently pulled from a selective pool of highly skilled scientists and armed forces personnel. In most cases these people have undergone years of intense training and psychological examination and have planned their lives around becoming space travelers. When space exploration demands greater numbers than what is maintained in the current limited pool we will see a diversification of personalities which may cause conflict.

The added pressures of conflicting personalities and the increased dangers of long term space missions could create problems that have not been widely experienced. Space travelers of the future will have unique needs including entertainment, food, environment, and psychological factors. Space dwellers will have different desires and will respond to environmental factors in different ways. Therefore the tools used to create environments must be adaptable to different people.

There is a significant amount of research about the subjective perception of sound and psychoacoustics. The intent of the current research is to apply this knowledge to the field of space exploration. This would include elements such as mood altering sound, designed to promote a healthy work rhythm and to fight off depression in harsh environments. In addition, the study will investigate noise reduction and the use of sound to dampen ambient noises that may become mundane or damaging to the ears after long term exposure. Space travel is similar to dangerous events on earth,

such as submarines and Antarctic missions. Both of these are dangerous and come with some degree of isolation and lack of privacy from fellow crew mates that may cause discomfort.

Previous Research

Research related directly to sound and music as it pertains to space travel is difficult to find. As a result, it is important that research from other related areas can be applied to space travel. For the purposes of this section it will be assumed that most research about sound and music performed on earth is applicable to space travel situations. For research that may need a more defined environment we will focus on research pertaining to capsule environments. The following sections are a justification for using research performed on earth to make claims about life in space.

Prisons

Space travel conjures images of an endless nothingness reaching out in all directions. Although space itself is never ending, the vessel that takes you there has very definite boundaries, and it's usually very confined. The confining nature of a prison makes it analogous to space travel. Prison populations consist of people from various social, economic, and educational groups and backgrounds. In future space travel, when crews are comprised of people from different backgrounds, there will undoubtedly be tension that effect and divide the team.

In an attempt to make reform in prison easier, prison authorities have instituted special programs, with many involving music. It is required that the crew of a spacecraft does not become too angered by their confining environment.

Music Research

For the purposes of this paper the fields of music research will be divided into categories. The first, music therapy has gained popularity since the 1950's. The second categories are the research which revolves around the authoring of music to aid in any act or to create pleasant environments.

Specifically we will investigate some of the ideas behind the company Muzak, which creates musical environments with the expressed purpose of trying to make people feel good, something extremely relevant to the field of space travel and many of the depressions and anxieties associated with it.

Arctic Bases and Submarines

A capsule environment is an artificial habitat created in order to sustain life in an otherwise lifeless location. A capsule environment is a subset of an isolated, confined environment (ICE), and in the case of space travel it also falls into the category of extreme and unusual environments (EUE) (Suedfeld and Mocellin 1987). An ICE is not always and EUE. Prisons are an example of an ICE that is not necessarily an EUE. Examples of ICE's that are EUE's are arctic and polar bases, submarines, and spacecrafts. The capsule in each environment may be different. The capsule may be moving, or it may be stationary; the environment may be changing or it may be consistent. However, "striking similarities seem to exist between the problems facing groups in the Polar Regions, space, underwater establishments, and expeditions...." (Ursien, et al. 1991).

Antarctic bases share a special connection with space exploration because of the inherent scientific implications. In 1961 the Antarctic Treaty was signed, suspending territorial claims and drilling, and removed all armaments. In addition, the area was opened to the building of any stations by any country in any area. This treaty dedicated the Antarctic region to scientific research. The dedication of an area to global science research is unique to Antarctica, and the current political climate of space.

In the case of the submarine it is likely that a crewman is always surrounded by people. A submarine is generally a cramped environment which requires many workers to keep it running. Privacy is a luxury whose cost is too great when preserving life is more important. The innards of a submarine are geared more towards the machinery that keep the crew alive and less towards the crew's comfort. Although submarines are getting larger and larger, their hallways are still repeating corridors of pipe and

wire. Similar statements can be said about space travel. The top priority is preserving the life of the occupants, even at the cost of privacy and comfort. (Antarctica Natural Laboratory and Space Analogue for Psychological Research)

Open Office Environment

There is no doubt that current space travel is far more stressful and demanding than nearly any work environment on earth. It is possible that space flights of the future may have many things in common with a modern office building. Future long term space flights may have large crews working on individual or team projects. The interactions between employees in an office and the crew of a space mission will be similar. At times crew members will need to concentrate on their individual tasks and other times they will need to communicate with other crew members to complete a job. These types of interactions are similar to those in an office environment. Just like an office environment, space missions require concentration to keep productivity high, and distractions must be limited.

Music in Space

Music is likely to be the most powerful tool for engineering the auditory environment in space. Music is easy to store, produce and customize. Music can have different affects for different people. For some music is energizing, for others it's relaxing. Space exploration is likely to be filled with dull and repetitive tasks, as well as tense and stressful situations. Music has the ability to overcome both of these obstacles as well as countless others. In the following sections we will explore the uses of music as well as ways in which to deliver and store it.

The Psychology of Music

How music can overcome problems with productivity, energy, work ethic, and mood

Music can be an effective tool for engineering productive environments. A company called Muzak has been in the business of mood alteration through music for nearly one hundred years and has become quite adept at providing specialized music sequences for various businesses.

> *"Audio Architecture is emotion by design. Our innovation and our inspiration, it is the integration of music, voice and sound to create experiences that link customers with companies. Its power lies in its subtlety. It bypasses the resistance of the mind and targets the receptiveness of the heart. When people are made to feel good in, say, a store, they feel good about that store. They like it. Remember it. Go back to it. Audio Architecture builds a bridge to loyalty. And loyalty is what keeps brands alive." –Muzak LLC*

The company refers to themselves as "specialists in the physiological and psychological applications and effects of music". The term that appears most often when researching Muzak is "Stimulus Progression". Stimulus progression refers to the process where the type of music is changed at regular intervals in order to increase the psychological effectiveness, see Figure 1. After the founder of the company, George Squire, found that playing music for his employees increased their productivity

a case study was done which supported the idea. As a result the BBC began to broadcast music with the intent of having it played to fatigued workers in World War II factories. (Muzak.com 2008)

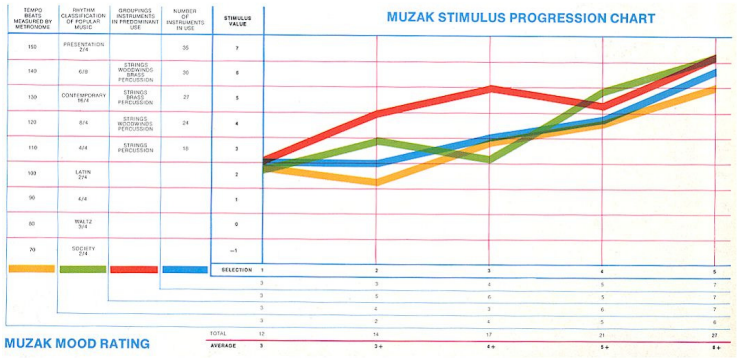

Figure 1 – Muzak Stimulus Progression Chart (Muzak Promotional Literature)

The Muzak Corporation later patented stimulus progression, an "elaborate system that arranges songs according to temp and time of day, taking into account the typical lulls that hit workers mid-morning and mid-afternoon" (Garton 1996). The patent describes the process as grouping music into quarter hour segments followed by quarter hour breaks. The music is grouped by intensity, using the notion that intensity is directly related to productivity. Songs receive ratings from 1-6 to indicate their intensity. The songs are chosen based on the time of day, according to the chart in Figure 1. The 24-hour plan provides more stimulation at 11 am and 3 pm, the times when workers are most lethargic. The songs slow after lunch and towards the end of the day.

> *"… music is art, but Muzak is science. And when you employ the science of Muzak: in an office, workers tend to get more done, more efficiently, and feel happier. In an industrial plant, people feel better and, with less fatigue and tension, their jobs seem less monotonous. In a store, people seem to shop in a more relaxed and leisurely manner. In a bank, customers are generally more calm, tellers and other personnel are more efficient. In general, people feel better about where they are; whether it's during work or leisure time. Muzak is all this and more. That's why we say Muzak is much more than music." – Muzak Promotional Literature*

Research has proven that careful programming of Muzak has increased sales at supermarkets, increased morale and productivity, and dissuaded shoplifting. Although unrelated to space research, in

the 1980's when Muzak was trial run at supermarkets a barely audible message of "I am honest, I will not steal" 9000 times an hour dropped shoplifting rates by 37%. (Secret voices: Messages that manipulate 1979)

Music can serve as an anxiety preventing or reducing measure. In a 2001 study music was used as a sedative during subjects' preparation of oral presentations. The group who prepared with music had notably lower stress levels, and also had lowered heart rate and blood pressure. (Lesiuk 2005)

Music preference is extremely important. The positive effect of music is lessened when it is not preferred by the listener. In a 1984 study Stratton and Zalanowaski found a strong correlation between the preference in music and the degree of relaxation. They concluded that preference for certain types of music as well having familiarity or past experiences accosiated with the music vastly increased its effectiveness at reducing stress. Stratton and Zalanowaski's research shows that the positive affects of music that have been discussed in this section are negated if the subject is unable to select musical pieces that are to their liking. (Stratton and Zalanowski 1984) (Thaut n.d.)

Creativity and the ability to produce work are both adversely affected by stress and mood. As discussed in previous sections, the environment of a spacecraft is likely to be filled with stressful situations. Changes in mood can occur from music listening when an individual begins projecting their past experiences on the tone and rhythm of a particular piece of music, positive associations enduing positive mood changes. This fact underlines the need for personalized music selection. Since music can be used to induce a pleasant mood and increased arousal, subjects will perform better at their tasks as a result of effective music. (Lesiuk 2005)

The crew of a spacecraft work in close quarters and in dangerous environments. These conditions require crews to work as a cohesive unit. In 2000 an article was written in the Topeka Journal regarding prison choirs. A retired conductor started a volunteer men's choir in a minimum security

prison. Inmates practiced twice a week and occasionally performed for the rest of the prison population. The goal of the choir was to help inmates assimilate back into the real world. The byproduct of the choir was a heightened comradery between inmates. One inmate stated "When I'm singing with these fellows, I don't look at race. We're one." (Ferguson 2000)

In 2001 a study was done exploring the role of music therapy in prisons. Five participants were selected who experienced drastic limitations to their physical freedom, including reality stimulation and a lack of emotional ties due to imprisonment. During the first session, the concept of music therapy was explained to the participants. The study consisted of 12 sessions of music listening. The first few sessions were open to everyone, but the remaining sessions were open only two participants who attended the first meetings.

The results of the study were positive. Self reported measures showed that participants felt increased levels of relaxation and decreased levels in stress. One inmate reported that she "really felt a part of the group and accepted…" (Daveson and Edwards 2001)

This study suggests that there were two benefits from the use of music therapy, the first being a strengthening of personal relationships and the second was a reduction in stress. These results are important in view of the anecdotal evidence of the personal and social problems that were observed during the Russian MIR space programs (Burrough 1998) as well as during other ICE missions (Palinkas, et al. 1973)

Sleep Studies

A lack of adequate sleep can cause many serious physical problems such as fatigue and lapses in concentration. These problems could easily place crew members in danger. Sleeping troubles can stem from anxiety, depression, and a variety of physical conditions. In 2003 a music based sleep study was performed using people with sleeping problems, as determined by the Pittsburg Sleep Quality index

(PSQI). Participants had PSQI scores ranging between 6 and 16 in both a control group and an experimental group. (See table 1 and figure 1 below, from music improves sleep in older adults). (Lai and Good 2004)

Test Date	With Music (PSQI)	Control (PSQI)
Present	10.97	10.2
Week 1	8.4	10.13
Week 2	7.73	10.17
Week 3	7.13	10.07

Table 1 – Sleep quality results with and without music (Lai and Good 2004)

The experimental intervention consisted of one of six possible forty-five minute 'sedative' music selections played at bed time. Participants were able to choose which track they wanted to listen to. Five of the tracks were western style and a single track was Chinese. All of the tracks fell in a beats per minute range of 60-80. The types were: synthesizer (new age), harp (eclectic), piano (popular oldies), orchestral (classical) and slow jazz. The results were exceedingly positive. The control group's PSQI remained nearly constant throughout the 3 week experiment while the music group exhibited a significant decrease in their PSQI stores, corresponding to a higher quality sleep. The results of the experiment have been plotted in the figure below.

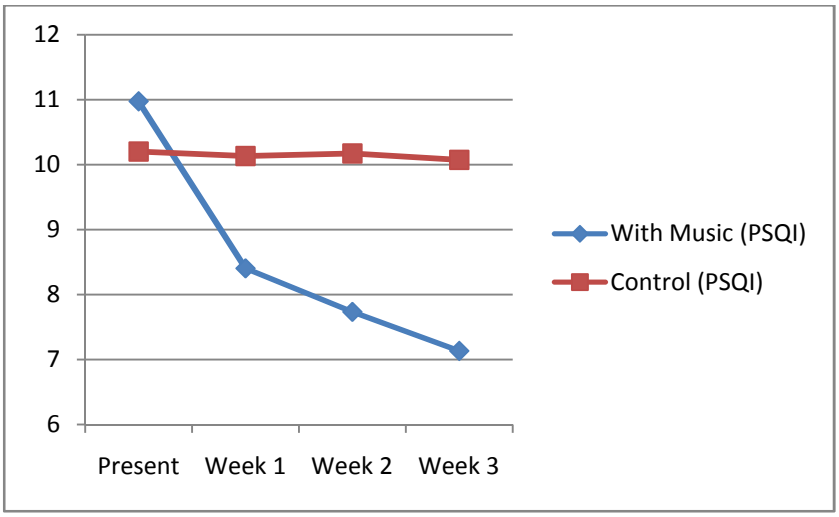

Figure 2 - Sleep quality results with and without music (Lai and Good 2004)

The Affect of Music on the Third Party Subjects

In the previous section it was found that music therapy was most effective when the music was preferred by the listener. It is likely also true that if the music is not preferred by the listener, or it is associated with negative passed experiences, than it may have a negative effect on the listener. The possibility of listening to music that is disliked is increased when quarters are closer, and coworkers are from varying backgrounds.

In 2004 a study was performed to test the affect of music on altruistic behaviors in its listeners. It was proposed that uplifting music would promote a positive attitude, and therefore the listener's tendency to be helping to others would be increased. Conversely it was proposed that listeners of 'annoying music' would be in a poor mood and less likely to be helping. The music was played to a group of individuals exercising in a gym, when exiting the gym they were asked to distribute leaflets for a charity. The results of this field test can be seen below. We see a serious decline in apparent helpfulness in participants who listened to 'annoying music'.

# Leaflets	Uplifting Music	Annoying Music
0	73	105
50	31	17
100	19	5
150	2	1
200	2	0
250	1	0

Figure 3 – Number of Leaflets Participants Were Will to Distribute (Adrian North 2004)

It can be said that the negative effect of 'annoying music' contributes to a negative mood change. In the same way that a pleasant mood increases productivity, a poor mood will decrease productivity. If the undesired music causes the subject to feel stress their work behaviors will suffer. An increase in stress will lead to a decrease in productivity. In addition to the drop in productivity; stress will often lead to depression, nervous breakdowns and even heart disease. (Management Services 2009)

The third party listener may also attribute the cause of their stress to the person who is listening to the music. This attribution is likely to cause tension between the parties. This tension between workers and crew mates will result in a breakdown of the team like relationship required for space travel. Productivity will eventually decline even further as animosity is bread between members of the crew. An annoyed worker will be distracted from their work. In a manufacturing job a distracted employee is an unproductive employee. In space travel a distracted crew member could cause serious bodily harm or death to themselves or other crew members.

Solutions

In the previous sections problems or positive effects related to music listening were outlined. The problems can be categorized as being either personal or interpersonal. Personal problems include issues like storage and playback, while interpersonal problems are issues like noise pollution.

Solutions for the Individual

The primary issues concerning an individual's ability to listen to music during a long term space mission are storage, playback, and customization of content. With a solid foundation in these areas listeners will be able to create a listening experience that is best suited for them. Combined with the proven psychological principles of stimulus progression the listener would have an automated music experience unlike any other.

Storage

Storage space, both physical and digital, is at a premium in space travel. The ability to store data grows daily, and with it comes the ability to store larger music collections. The ability to store data has grown significantly faster than the ability to compress music files. In 2000 the cost of storage was approximately $8 USD/Gigabyte. In 2007 that price dropped to around $1 USD/Gigabyte. The cost of storage since 1988 has decreased by approximately 1000%. If we use this information to infer the cost per gigabyte in the year 2037, the year announced the NASA's administrator as the possibly first mission to Mars, we see that the cost for storage could be as low as $8.73E-11 USD/Gigabyte (NASA aims to put man on Mars by 2037, AFP article). At this price $1 USD could buy over 11 Billion Gigabytes. Even with the limitations of the current common music compression abilities, with a compression ratio of 9:1, over seven trillion songs could be stored.

With storage space to fit 7 trillion songs a space mission could keep a database containing every song ever recorded ensuring that the content desires of each crew member are met. With a system like

this there would be no need to have individuals collect and store their own music. Instead everyone could listen from the collective database.

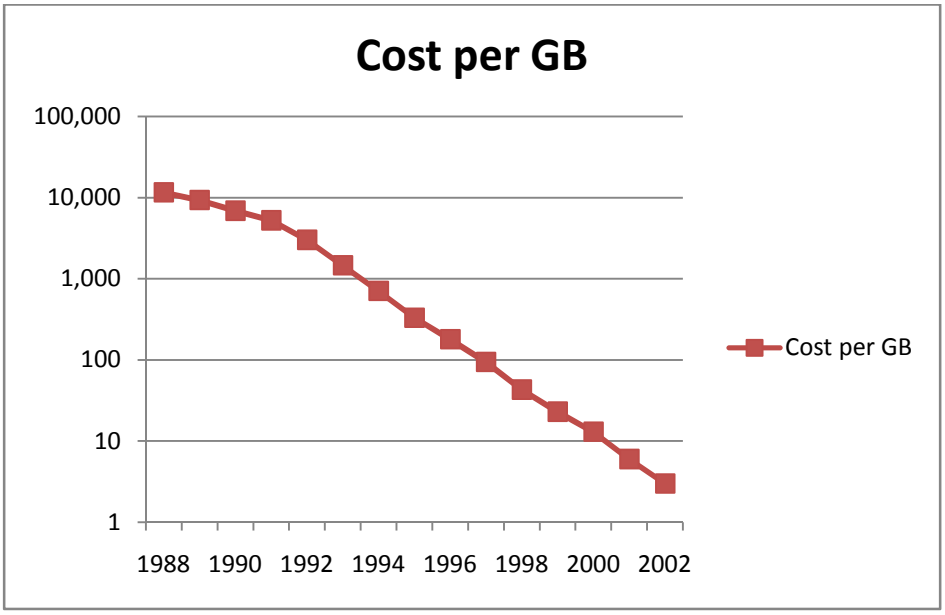

Figure 4 – Cost Per Gigabyte vs. Year (P Lyman n.d.)

Automated Content Choice and Stimulus Progression

While it should always be an option that the user be allowed to pick any piece of music that they wish to listen to, the process of sifting through a nearly endless database of music may because tiresome. With such a vast collection there needs to be automated methods of picking music. In addition to simply picking music that the system believes the listener will enjoy there should also be the ability to streamline the process of stimulus progression into the automated choice.

Users should always have the ability to build lists of their preferred music manually. Some of the more strait forward ways of selecting music would be by title, artist, genre, decade, region, etc. This manual selection process should be the basis for the automatic selection routines. User selections should be tracked and similar songs should be added to their catalog. The criteria for selecting similar

songs can be varied. Similar songs can be by the same artist, songs with the same beat structure or rhythm progressions, or songs that were given high ratings by reviewers of other songs which the user had manually selected. The listener should also have the option to rate the automated selections, increasing the accuracy of the automated system.

In order to gain more of a psychological affect from the use of music the principles of stimulus progression can be applied to the listener's customized list of songs. In stimulus progression all songs are given a numerical value for their intensity and the intensity of songs is varied throughout the day according to figure 1 in the first section. The intensity is determined by a mixture of the song's tempo, number of instruments, and rhythm complexity. The system that plays back music for all the crew members needs to have the ability to determine these three factors for each song. Now that all songs have been given an intensity rating and have been added to the users customized playback lists a stimulus progressed playlist can be generated using only songs that are appealing to the listener. This should increase the effectiveness of the stimulus progression idea by ensuring that the listener enjoys the music choices. With this system, as well as all of the other music systems, the user should be allowed to override any automated decision.

Automated Audio Traversal

The ability to track the position of crew members will likely be a part of the spacecraft's computer system. There are countless reasons that the position of all crew members would be important, an example would be to determine whether the entire ship had been evacuated during an emergency. There are many ways to track users within the ship; one possible way would be the use of RFID tags. Each crew member would have RFID tags built into their clothing, or special arm bands and a series of RF reader's position throughout the ship would track the location of these RFID tags. This is

technology we have now, and a person tracking system of the future would probably be more sophisticated.

The user's listening experience should be seamless. Regardless of where the user is positioned on the ship their music content should follow them. Besides equipping every crew members with a set of head phones, speakers can be incorporated into the spacecraft's design. Specifics in the types of speakers and content delivery systems will be discussed later. With this ability the spacecraft's computer could also ensure that music would not be accidently left on in unpopulated areas of the ship, and the amount of time that users would be forced to listen to the music of fellow crew mates could be minimized.

Content Delivery

The major goals for the content delivery systems are seamless integration with the ship, little to no noise pollution, and the general comfort of the crew. Music systems should be as non-invasive as possible, it should be a system that is used but never thought about. While headphones and conventional speakers work well at delivering sound, they fall short in these new areas by virtue of being too cumbersome.

Specialized speakers are one way of realizing some of these content delivery goals. Some new speakers systems use bone conductivity to transmit sound through the jaw bones. Other systems use highly directional speakers that project sound in a very fixed area.

There are many types of directional speaker systems. One type of directional speaker system is the sound dome. Sound domes direct their sound directly down on anything below them. The dispersion of the noise can be changed depending on the design of the dome. These domes could be positioned over common work areas, or placed in a line to create a row of unified sound.

Figure 5 - Sound dome (BrownInnovations.com)

Another type of directional speaker uses an antenna like device to project audio long distances with a very narrow dispersion. A company called American Technology has a device that emits what they call Hypersonic Sound. With a Hypersonic Sound device you can project sound over 100 yards with only a few feet of dispersion. A Hypersonic sound device could be used to provide sound down an entire hallway, but not in adjacent rooms, or it could be attached to a positioning motor that could be computer controlled to move with its target.

Figure 6- A hypersonic sound device has been placed in this mall display (ATCSD.com)

Another way to send directed sound is to use bones to conduct the vibrations. Instead of transmitting sound waves through the air, devices that use bone conductivity transmit sound directly to the user. The listening device is placed against the side of the head and vibrates the skull; the vibrations eventually make their way into the auditory system.

This method of delivering sounds has many benefits over traditional speaker systems. Just like directional speakers, bone conductivity devices can be used to deliver sound to a single person even when many people are present. A benefit bone conductivity devices have over traditional head phones is that they do not have to be worn over the ears. This allows the user to be able to hear important information around them even while wearing the device. Because bone conductivity devices don't use sound waves, they can be heard even in noisy environments.

The headset is the most commonly used bone conductivity device. Very similar to traditional head phones, these devices are worn on the head and near the ear but not on top of the ear. A more unique bone conductivity device is the pillow speaker. This device transmits audio directly to the listener with built-in bone conductivity speakers. Such a device would allow crew members to listen to their personal music while in their beds, which may be in close proximity to other crew members, while not polluting the room with noise.

Figure 7 - Bone Conductivity Pillow (Foo 2004)

Ambient Noise

Background, or ambient sound and music, is an important aspect of environmental design. It is the reason libraries are quiet, and apartment buildings are built to block noise from other tenants, sound can be very annoying. It's the reason sleep machines play sounds of the ocean, or crickets, or a babbling brook, sounds can be relaxing. Future space travel should be designed with these considerations in mind.

Types

For the purposes of this paper we will divide ambient noise into two categories. The first is damaging ambient noise. This type of ambient noise could be generated by high voltage electrical devices, or the droning of a motor. The second type is annoying ambient noise. These noises can be generated in the same way as the damaging noise, but can also manifest as neighboring conversations or loud undesired music.

Damaging Ambient Sound

A healthy human ear can hear in a frequency range of 20-20kHz. Sound outside of this range is not necessarily damaging, but it is inaudible. The intensity of sound is measured by its pressure, in decibels. The average person can hear down to 0db, the pressure produced by leaves rustling. Some can hear down to -15db. Sounds above 85db can cause permanent hearing damage. The other important factor when calculating potential hearing loss is exposure duration. 85db is approximately the sound level on a busy street, or an idling bull dozer. Hearing loss will occur after 8 hours of exposure at this pressure level. This sound level could also be generated by running motors from a number of pieces of machinery.

Anticipating damaging noises in future space missions is a difficult task. Common sources of damaging noises are engines and other general machinery. It is possible that machinery used now will

be outdated when these long term space missions are conducted, and new machinery may run completely silent. The main engine of a spacecraft is likely to loudest noise source on the vessel. Even though this engine is loud it doesn't necessarily make it a target for redesign. In space missions the ship only needs to fire its main engines until it reaches its final speed, limiting the damaging effects of the main engine to take off and major trajectory changes.

Table 2 – Predicted Hearing Loss (Dangerous Decibels 2009)

Continuous dB	Permissible Exposure Time
85	8 hours
88	4 hours
91	2 hours
94	1 hour
97	30 minutes
100	15 minutes
103	7.5 minutes
106	3.75 minutes
109	1.875 minutes
112	.9375 minutes
115	0.46875 minutes

Annoying Ambient Noise

Many new studies indicate noise as the greatest factor reducing worker productivity (American Society of Interior Designers n.d.)Identifying annoying noise is more subjective a task than indentifying damaging noise. While annoying noises can also be damaging noises, like the example of an idling bull dozer, the two are not necessarily the same. An annoying noise may be produced by a running generator that is below the damaging level. Other annoying noises may be background conversation, radio chatter, or undesired music. The final decision whether a sound is annoying or not comes down to the individual. Regardless of whether the noise is found to be annoying, it will affect concentration and productivity. In a space environment, lapses in concentration could lead to serious injury or death.

Research shows that the most disruptive noise in a work environment comes from the face to face conversations of coworkers. The conversations that are most distracting are the ones where most words can be overheard and most sentences are intelligible. Even a ringing telephone is rated lower in aggravation level (American Society of Interior Designers n.d.)

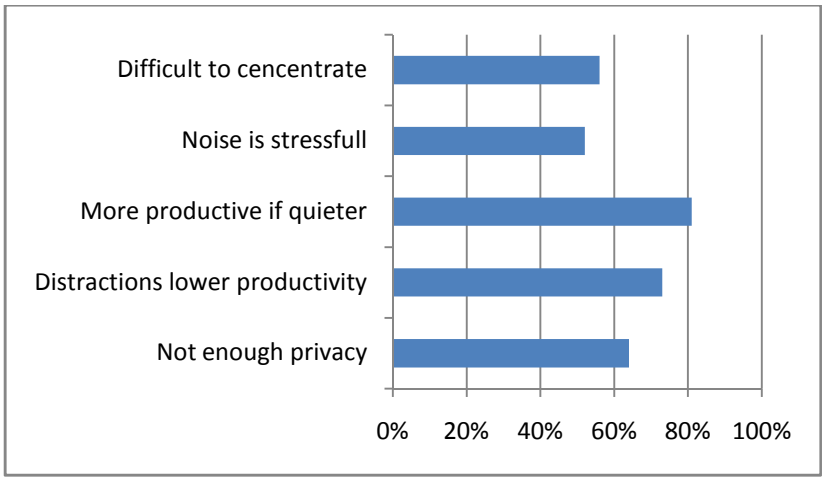

Figure 8 – Office Productivity Polls (American Society of Interior Designers n.d.)

Solutions

Some of these ambient noise problems have unique solutions, while others have solutions that apply to multiple types of noises. One solution is active noise cancellation, to nullify the obtrusive noises. Another is damping, to reduce the reflections of noises and decrease the overall background noise level. The third is design, reducing distracting and damaging noises by removing them from key positions.

Noise Cancellation

Noise cancellation or active noise cancellation, is the process of nullifying sound by producing a sound whose phase is 180° from the offending noise. A noise cancelling device generally consists of a microphone array which reads in the offending sounds, a processor which determines what noises should be masked, and a speaker array to produce the phase shifted duplicate. Both the speaker and

microphone arrays can be created using untraditional mechanisms, like vibrating devices that are attached directly the frame of an enclosure. (Elliot 1999)

Active noise cancellation can be combined with desired noise sources. Music and sound generated for noise cancellation purposes could be outputted using the same sources. By combining noise cancellation into the system that produces desired sound, like radio communication or music, the noise cancellation system can differentiate between desired and undesired signals. This would allow the noise cancellation system to leave a room silent, or leave it with only desired sound content.

Active noise cancellation is best used in small environments, or in conjunction with headphones. When used with headphones, active noise cancellation uses a microphone placed inside the headphone to compare the sound that the listener is hearing to the sound that the headphones should be producing. The technique has also been used with moderate success in large cabin environments such as the inside of a propeller plane where cabin noise was diminished an average of 7 dB. Noise cancellation system can also be installed to cover small, directed areas such as a cubicle or a bed.

A company called Packet Video created a test bed with an integrated active noise cancellation system in a 2006 experiment. The group was able to place the noise cancellation equipment into the headboard of a twin bed and documented excellent noise reduction for both repetitive noises, like engine noise, as well as complex noise such as snoring. The figure below shows a plot of their data where a 15dB reduction in snoring noise is exhibited. (Yenduri and Chakravarthy 2006)

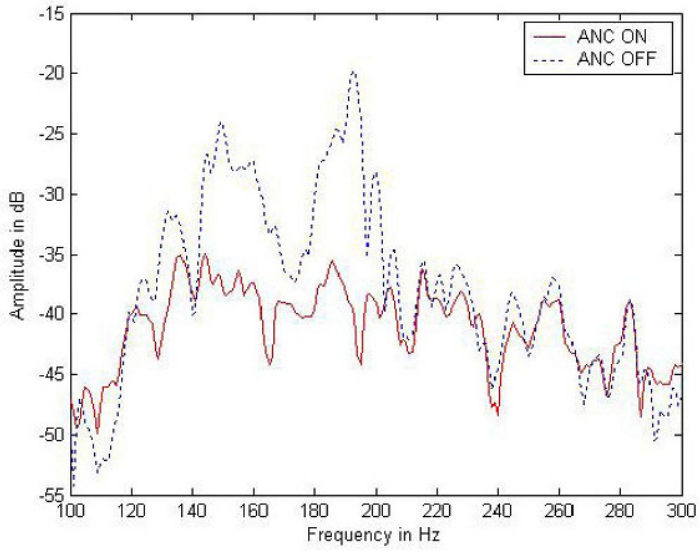

Figure 9 - Reduction in snore noise with ANC (Quite Comfort beds with electronic noise reduction) (Yenduri and Chakravarthy 2006)

Sound Screening

If removing the noise source is not an option then masking it with additional noise may be the solution. As discussed earlier the most annoying and distracting noise in an office environment is background conversation. Background conversations are most distracting when most words and sentences are intelligible to the listener. To remove the distraction component the background conversations can be made unintelligible by drowning it out with neutral noises.

Acceptable neutral noises are subjective to the listener. Sound screening devices exist in commercial markets today in the form of white noise generators to aid with sleeping. White noise may not be the best choice of sound to drown out background noise while working, but other nature noises like babbling brooks and crashing waves may work well and have an added calming and soothing affect. Of course music is also an option. Sounds masking systems are generally set at 48 dB. This level is used as it ensures conversations remain private while not becoming a distraction itself (American Society of Interior Designers n.d.)

Sound Damping and Environmental Design

If an annoying noise source cannot be cancelled, removed, or masked then the only viable option may be to diminish the noise using careful environmental design. The first issue that concerns the propagation of noise when discussing environmental design is the layout of the structure and the placement of noise source. The second concern is the type building material and its noise absorbing properties.

The layout of a structure can affect noise propagation in two ways. As discussed in earlier sections a common source of disturbing noise is machinery. Care should be taken to keep work and living areas as far from machinery as possible. The technical needs of a spacecraft may limit the ability to remove loud machinery from quiet environments, but this fact should not remove the topic from consideration.

A more practical use of structural planning, for the purposes noise damping in spacecraft design, would be the limiting of noise propagation through the use of indirect paths. When a line of site exists between loud and quiet areas, sound has an easier time passing between the two locations. By using indirect paths, loud or annoying noises would be diverted from quite areas. By ensuring that entrances to quiet areas are placed on the sides of hallways, as opposed to the end of the hallway, sound waves propagating down the hall will be less likely to cause noise pollution in sensitive areas.

Avoiding line of site between loud and quiet areas is not limited to inter-room noise pollution. Line of site issues can exist is closed work environments also. If teaming areas coexist with individual work areas then care should be taken to ensure that dividers of adequate height are used to contain noise created by the teamwork. These dividers do not need to be constructed in a traditional office

environment fashion. Building and moving cubicles in a spacecraft would not be a practical solution, so dividers should be designed into the construction of the ship.

In order to achieve normal privacy, a sound level where background conversations are not distracting, a divider must be at least 65 inches high. This divider height would be different depending on whether the spacecraft had artificial gravity or not. In a spacecraft with artificial gravity the dividers would have the 65 inch requirement. In spacecraft without artificial gravity this requirement would be much different. In a room significantly larger than 65 inches, and without gravity, dividers would need to stretch from floor to ceiling, which may be impractical.

In addition to divider height requirements and the removal of line-of-sight paths, noise propagation can be limited with the use of materials with a high noise reduction coefficient. In order to achieve normal privacy a noise reduction coefficient of 0.6 is required. While the choice of material for sound proofing dividers is important, a more important decision is the material choice for walls, ceilings, and floors. In an office environment an easy choice for floor coverings is carpeting. Finding carpet with high NRC is an easy task. The choice of ceiling material in an office environment is also an easy decision, as many drop ceiling tiles are available with a high NRC.

In a spacecraft these decisions may be more difficult. Material choices may be restricted by technical considerations such as weight, or sterility. Noise reduction material options may be limited to coatings, such as paints or tiling. When ceiling systems are designed, things like light fixtures or ceiling shape can be taken into consideration. Broad and flat surfaces should be avoided, as they cause excessive noise propagation. Ceilings can be designed with a taper, to reflect noise to the walls. Flat light fixtures, like those used for fluorescents, should be avoided. Parabolic fixtures can be subsisted for hard plastic lenses. (American Society of Interior Designers n.d.)

Scenario

The research in this paper will likely be added to a compilation of documents whose goal is to aid in the design of both long term space vehicles and the missions themselves. It is very possible that this particular compilation of research may be overlooked for more traditional papers. This scenario walk through will take parts from the previous section and compress them for quicker study.

In the weeks before a long term mission, crew members are asked to use specialized music player software. The software will access a near limitless database of music. The music preferences of the crew members is stored and analyzed.

At the start of the missions, crew members are fitted with a small life-signs monitoring system. This device is capable of tracking temperature, and heart rate as well as the location of the crew member. The vital signs of the crew members are available not only to the medical staff, but also the environmental systems.

Crew members traversing the corridors of the spacecraft see a series of directional panel speakers built into the walls or ceilings. As the crew members move through the corridors; tracking systems follow them, delivering sound specifically for them using the nearest directional speaker panel. The personalized sounds do not spill into adjacent areas because the halls are constructed of materials with a high noise reduction coefficient. The halls also lack flat surfaces or parabolic light fixtures, which could undesirably reflect noise.

Not all areas of the ship are lined with panel speakers, as some areas are too large or have irregular construction. Some of these areas are lined with mechanically actuated panel speakers, similarly designed to the HyperSonic™ speaker system. These speakers will lock-on to their target and

follow them. The extremely directional nature of these speakers will ensure that sound is only delivered to the intended target.

In other areas even actuated speakers are not appropriate. Crew members are also outfitted with bone conductivity hearing devices as well as conventional listening devices, for two way communication. The device does not sit directly on the ear, allowing face to face conversations to continue uninhibited. Bone conductivity devices will allow the crew to hear important messages even in noisy environments. The listening device on each crew member is monitored by the communication computers. Since all sounds, excluding personal conversations, are supposed to be generated by the computer, sound heard by the listening device that is not generated by the computer can be flagged as noise. Area speakers can then be used to attempt to cancel as much of the noise as possible.

In stationary work environments, such as desks or consoles, moving speakers will not be required. Devices such as sound domes can be incorporated into the ceiling above highly trafficked work areas, allowing the worker to hear their audio clearly while limiting the amount of noise pollution.

Crew bunks can be fitted with several different audio devices. Speakers and listening devices can are fitted into the headboards and foot boards for the purposes of canceling out sleeping noises, such as snoring. Directional speakers, like the sound dome of panel speaker, are used to provide audio content for a single sleeper. Even less traditional speakers, like bone conductivity pillows, are used to completely eliminate noise pollution from a bunk.

Conclusion

Considering the major obstacles between current orbital space travel and future inter-planetary space travel that currently plague us, it seems out of place to discuss a strategy for sound design. Initial thoughts on the matter would say that all efforts should be focused on creating the vehicles and engines that will take us to distant planets, and not fuss over the seemingly unimportant. This is an incorrect evaluation of the situation.

The goal for long term space travel is not only to create the vehicle that gets us there, but to have a successful overall mission. The standards by which one judges a mission to be successful will ultimately vary between people, but there are some undeniable aspects that need to be met. Initial long term missions will likely be with manned by the most trained personal possible, because there is no telling what could go wrong. It could be expected that the first long term space missions will be extremely stressful for the crew. It is even possible, and probably more likely, that there may be crew deaths during initial missions. The future goal of long term space missions is to make them a common occurrence; much like a commercial jet flight is today. It would be expected that at the end of a commercial jet flight no passengers would be physically harmed, but the mental health of the passengers is not even considered anymore because the event is so accepted. This is a goal for future long term space missions in order to make them be successful.

One of the ways this can be accomplished is with careful sound design. When missions grow longer and longer, even small annoyances can become huge problems. Ensuring that the crew is comfortable, with regards to the audio environment, can help ensure a successful mission. Audio can also be incorporated to ease stress and increase productivity, allowing the crew to get more out of their time.

Audio applications for space missions are endless. This research has only scratched the surface of available design ideas and criteria. The data and research that has been presented should be used as a springboard to aid in future designs of long term space vehicles and program. If nothing else, this research should at least plant a seed in designer's minds that the audio environment of a long term space mission is integral to its success.

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