GLOBAL AUDITORY CONCERNS FOR INDIVIDUAL NEEDS: EXPANDING THE HEARING CONSERVATION UNIVERSE TO THE INTERNATIONAL SPACE STATION

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ABSTRACT

When a hearing conservation program (HCP) involves NASA's astronauts and their unique working environment, special acoustical concerns develop that are receiving heightened attention from medical, safety, and engineering teams. The presence of distinctive characteristics (like prolonged noise exposures in weightless environments) associated with these high-visibility spaceflight programs requires adaptation and integration of strategies that have been effective in ground-based environments. This presentation will address recent developments in NASA's flight crew HCP, focusing not only on risks of noise-related hearing loss, but also on concerns for task performance by individuals working in acoustical environments that are disruptive to communication, sleep and mission effectiveness. As a result of lessons being learned on Space Shuttle and International Space Station (ISS) missions, information will be presented that may contribute to program management in more conventional hearing conservation settings.

INTRODUCTION

Among the attendees at this NHCA conference exists an incredible wealth of working experience and successful hearing conservation practices. Senior and junior HCP managers alike are individually working with great focus in their day-to-day operations, facing (and often re-facing) complicated program management issues. When joined together in a major conference such as this, we can collectively benefit from this continuing education opportunity as we pause and get a fresh perspective on this process, from a distance. While at this conference in Dallas, you may be as close as 25 miles -- or as far away as 2,500 miles -- from your home program, where your HCP may have many thousands of noise-exposed personnel. Recently, public media attention has been directed to the reported presence of noise-related problems aboard the ISS, which has a

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HCP that is uniquely small (with only 6 noise-exposed American astronauts aboard the ISS last year) and distant (over 220 nautical miles above the earth's surface) from us. However, from that porthole, the day-to-day predicaments of HCP management become even more obvious. The distinctive characteristics associated with these high-visibility spaceflight programs require the integration of strategies that have been effective in ground-based environments, yet are adaptable to accommodate the uniqueness of "on-orbit" noise exposures.

The purpose of this presentation is to review some "lessons learned" in NASA's Space Shuttle and ISS missions that may contribute to program management and clinical activities for more conventional hearing conservation programs. This presentation will address recent developments in NASA's flight crew HCP and focus on problem-solving strategies being employed. Perhaps you may discern an application (or reminder) that can reinforce your personal HCP activities.

BACKGROUND

On November 19, 2001, television's Cable News Network broadcast a story headlined "Astronauts Endure Nonstop Racket from Fans and Pumps," in which it was reported that noise levels aboard the ISS were high enough to interfere with the detection of an activated fire alarm by the mission commander. This brought ISS noise issues to the public's attention, as has a recently published scientific article (Buckey, et al. 2001). The most obvious concern was an awareness that noise levels aboard spacecraft may be causing temporary and permanent hearing loss after long-duration spaceflights, but since then, other more subtle human health factors have become relevant. Acoustical issues in human spaceflight are now receiving heightened attention at NASA, bringing hearing conservation to a much more visible presence among its medical, habitability, safety and operational organizations. These groups are concerned not only with the potential risk of noise-related hearing loss, but also with crew performance due to interference with communication, sleep and mission effectiveness.

The ISS is an on-orbit laboratory that provides experimenters with permanent space facilities and services in support of scientific research on the effects of weightlessness (or "microgravity"). Scientific objectives for each proposed experiment are translated into engineering requirements and then into hardware designs that must meet a vast array of operational, safety and logistical criteria. The resulting experiment payloads interface with the ISS via a system of semi-permanent host "racks," which provide subrack payloads with common power, utility, health-monitoring and data connections for the duration of the payload's residency on ISS. The habitable area of the ISS consists of a series of separate room-sized laboratory modules that house experiment racks, as well as the complement of non-research hardware (such as ventilation, refrigeration and physical fitness exercise equipment) required to sustain on-orbit operations.

Each three-to-four month long mission has involved a multinational crew of three astronauts who are responsible for operation of the experiment hardware and for performing routine system maintenance tasks. Before launch, each crewmember has undergone an exhaustive selection and training process, spanning more than 3 years, at a cost of approximately 2 million dollars. Obviously, the medical status and readiness of these exceptional individuals is of paramount importance to the agency and its mission.

LESSONS RE-LEARNED IN NASA'S EFFORTS

Even though the size of the astronaut hearing conservation program is small (with 138 active American astronauts), its high visibility, related training costs and unique environment present an extraordinary laboratory for employing hearing conservation principles that have been tested and proven previously, such as those outlined in the following sections. These principles warrant review and consideration by *all* hearing conservationists, since thinking "out of the box" often means first realizing the presence of a "box" and then comprehending a potential to extend those boundaries. [Certainly, the list of principles discussed here is not as all-inclusive as The Noise Manual, by Berger, et al. (2000), but hopefully is as practical in content].

Hearing Conservation is a Multi-Disciplinary, Team Effort

Subsequent to its review of the ISS noise situation, NASA's Johnson Space Center has recently become aware that nearly a dozen separate acoustical engineering, medical, safety, flight crew and payloads organizations considered themselves to be "primarily responsible" for resolving astronaut noise concerns, yet their efforts were largely separate and, therefore, less than optimally effective. For example, resources, data and results were often unknown to all players and not always shared, causing efforts to be duplicated. Individually, knowledgeable personnel were unable to meet their own potential. Once these organizations and resources were combined, their team efforts hastened productivity and achieved successes that had been inaccessible when each performed alone in their hearing conservation efforts. No audiologist, acoustical engineer, occupational health nurse, safety manager, or physician on earth, either, can individually succeed without teaming with related disciplines in addressing hearing conservation.

Plan Early, Before Irreversible Dilemmas Occur

The birth of the current ISS began in 1995, when the U.S. Space Shuttle originally docked with the now-decommissioned Soviet Mir station to form an orbiting, long-duration laboratory for research in engineering technology development, life and microgravity science, earth science, and space science. Since then, dozens of additional U.S. launches have extended the ISS to its current configuration. The addition of each segment (as well as each individual experiment payload) takes several years to progress from conception to launch.

In an effort to prevent hearing loss, enable clear speech communication and ensure a comfortable working environment on board the ISS, a set of design specifications limits acoustic emissions of all classes of equipment and hardware. These specifications employ the use of well-known NC (noise criteria) curves, against which frequency-dependent maximum sound pressure level emissions are compared. The NC rating system is a family of approximate equal loudness curves (See Figure 1.) commonly used in architectural acoustics to rate the ambient noise environment of an unoccupied space caused by the operation of ventilation and other building systems. The ISS has adopted NC criteria to help manage the spectral characteristics of its acoustical environment. This management takes place by minimizing the presence of tones, low frequency (often tactile) noise heard as rumble, and high frequency hiss.

A module-level specification issued by ISS limits the total noise spectrum due to continuous noise sources. Then, based on assumptions about the number, character and duration of the noise sources in a laboratory module, a noise “budget” is developed to govern noise emission from individual pieces of equipment. Thus, payload developers are encouraged (as you encourage your industrial plant managers) to manage the noise emission of their equipment so that the total integrated noise emission (and thus the noise exposure dose) are minimized. As in any industrial application that you may encounter in your hearing conservation programs at home, noise represents wasted energy, generated by inefficiently designed (or operated) processes or equipment.

The ISS noise emission budgeting philosophy has resulted in the specification of an NC 50 limit for the entire U.S. module and a rack-level limit of NC 40 for every rack (and sleep station) that resides in the module. The 60-dBA specification for the Russian Service Module approximates NC 55. A summary of ISS noise emission specifications is shown in Table 1.

Although acoustic emission specifications have been clearly articulated and published (NASA, 2000), payload developers frequently request waivers for experiment hardware that exceeds the spectral limits. In addition to the contribution of individual science experiment payloads, which may generate noise for short periods of time, the ambient environment is heavily influenced by noise from a treadmill (77 dBA, as reported by Clark, in press) and cycle-ergometer (80 dBA). Both are intended to maintain their presence on ISS as permanent and ubiquitous auditory reminders of the acknowledged importance of equally critical medical goals: preserving cardiovascular and bone health.

Continuous noise levels within the habitable portions of the ISS have been documented in the range of 56-69 dBA (Clark, in press). Roller and Clark (in

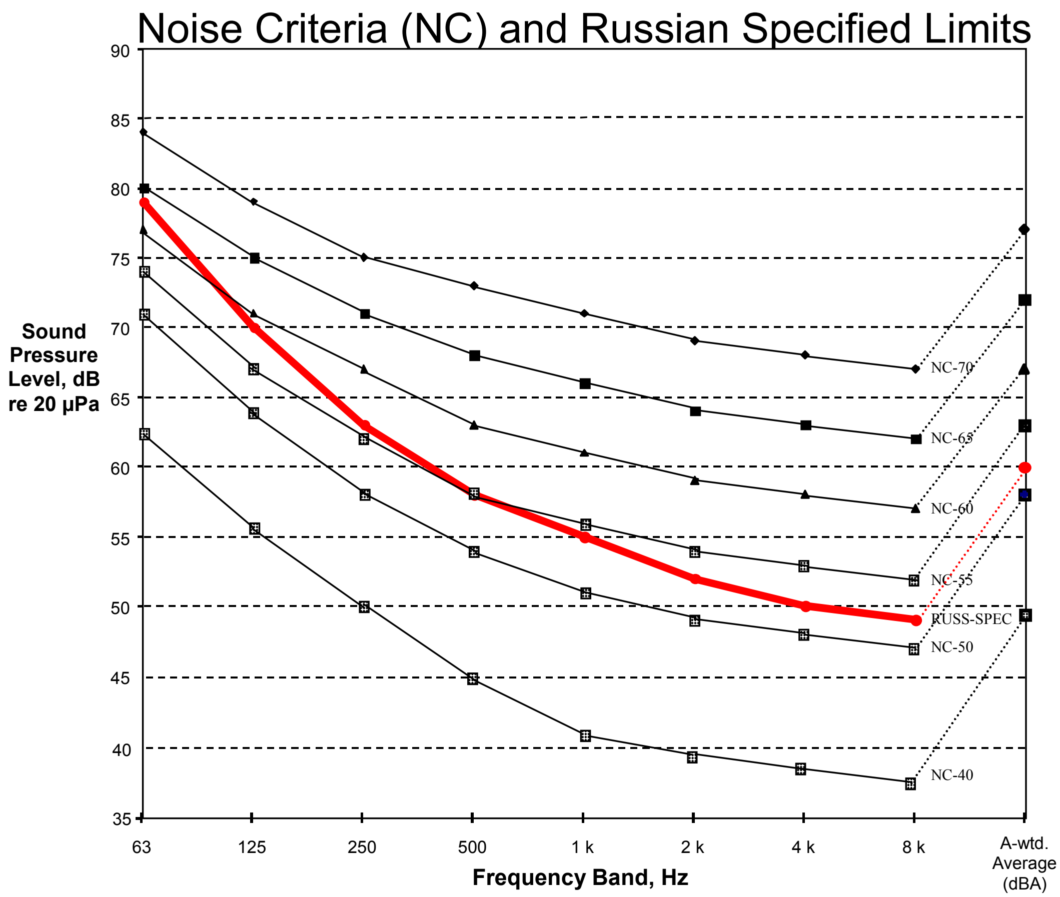

Figure 1. ISS Acoustics Design Specifications Summary (Clark, in press)

Table 1. ISS Acoustics Design Specifications Summary

Design Requirements		US Module Specifications	Russian Module Specifications	Payloads and other Hardware
Continuous Noise (more than 8 hours)	Awake Hours	NC-50	60 dBA	NC-40
	Sleep Hours	NC-40	50 dBA	Not Specified
	Hazardous Limit	85 dBA	Not Specified	Not Specified
Intermittent Noise (8 hours or less)	Hazardous Limit	Not Specified	Variable based on duration 65dBA for 4 hr *up to* 80dBA for ½ hr	Variable based on duration 49dBA for 8 hr *up to* 79dBA for 1 min
Impulse Noise (one second or less)	Hazardous Limit	140 dBA	Not Specified	Not Specified

press) report that, “astronauts are exposed for significant amounts of time to noise levels up to 70 dBA and at times even higher.” The US module, with measured levels of 56-60 dBA (Clark, in press), has received a waiver of the NC 50 requirement, as has the Russian Service Module of its 60-dBA criteria (with measured levels as high as 70–75 dBA, as reported by Buckey, et al., 2001).

When faced with an impending date for launch, NASA engineers and project managers face problematic dilemmas if the design of experiment payloads has not incorporated noise emission standards before hardware development is so far along that noise control efforts are difficult and expensive. Here again, countless conventional hearing conservation programs have been convoluted by insufficient, early consideration of noise issues.

Current Noise Standards May Not Apply to Contemporary Working Scenarios

While OSHA regulations and NIOSH noise criteria were originally based on damage risk criteria that considered noise exposure during a “work week” of 5 days of 8 hours’ duration, current ground-based work shifts (from 10 to 12 hours long) don’t necessarily match those parameters. The ISS presents an even more challenging puzzle, since the astronauts are exposed to noise for 90 days or more, without relief. Use of hearing protection is not a viable long-term solution aboard the ISS because of communication needs and such long-duration exposures. There is currently some discussion concerning the possibility that missions could be extended to a 6-month tour. Such long-duration noise exposures are not unlike the unique hearing conservation problems faced by the U.S. Navy, which places military personnel on board aircraft carriers and submarines, with little auditory rest from noise exposure.

The Relentless Pursuit of Identifying Noise-Related Hearing Loss is Not Straightforward

Although the key question being asked is, “Could noise exposures on long-duration flight cause hearing loss?” the small number of observations aboard ISS has limited statistical power. Clark (in press) and Buckey et al. (2001) recently reported that Russian space experiments have suggested TTS in the 4-6kHz range among all 33 cosmonauts on the Salyut 6 space station (which had acoustical environments of 70 to 76 dBA, greater than the ISS), with PTS demonstrated in at least one ear among 27 cosmonauts. However, U.S. experiences on Skylab did not reveal hearing loss among members of the crews evaluated. Roller and Clark (in press) retrospectively compared audiograms obtained from 386 astronauts (testing before flights, 3 days after landing, and 8 months later), as well as data from seven astronauts from STS-40 who were tested on Day of Landing (DOL) in 1991. Although they reported statistically significant TTS on DOL, the reported mean TTS was only 4.6 dB (considered to be within clinical test-retest reliability re: audiometry), with even less obvious trends in PTS. Recently, Clark and his colleagues have been seeking a reliable mechanism for on-board audiometric testing, to document any possible TTS during the duration of the flight. The difficulties presented by that challenge are similar to those we face on earth: measurement error (since the astronauts would be "testing themselves"), calibration error, background noise levels and limitations in using conventional audiometers that have not undergone exhaustive (and expensive) equipment tests to earn flight-qualified status. For those of you frustrated by ambient noise levels in your mobile audiometric vans, consider the trials of testing within the planet's most remote mobile van!

Hearing Loss May Not Be The Only Motive For Noise Reduction

For many years, Army audiologists sought their commanders' support for military hearing conservation programs with an emphasis on the cost of disability payments paid for service-connected hearing loss. Eventually, they learned that this technique did not win adequate attention from senior Army leaders, since those payments were NOT a fiscal responsibility of the Army, but a separate government agency (i.e., Department of Veterans Affairs). Seeking support for military hearing conservation efforts, the Army Medical Department changed its strategies to emphasize, instead, the importance of good hearing on mission effectiveness (e.g., being able to detect auditory threats on the battlefield, or vulnerability to fatal errors due to radio miscommunication). Similarly, noise may have other consequences on NASA's mission effectiveness than hearing loss alone. Historically, astronauts have complained that high noise levels on board spacecraft have caused headaches, inability to hear alarms, and interference with communication (Clark, in press). More recently, Roller and Clark (in press) cite reports that excessive noise on ISS creates problems in the areas of sleep, annoyance and speech interference. In particular, noise levels in the sleeping areas interfere with the crew's ability to remain asleep during intermittent bursts of noise (Oberg, 2001). As a result, acoustical issues are becoming far more critical on the ISS than when hearing loss was perceived as the only threat. Disruptions of crew efficiency and sleep are now recognized for their negative effect on performance and teamwork. Furthermore, this new approach has fostered recognition that airborne noise may affect animal experiments and that noise-induced vibrations may influence acceleration ("microgravity") measurements or disturb sensitive experiment hardware, thus affecting the acquisition and quality of scientific data.

Systemic effects on productivity/performance may be the key to high-level attention to acoustical issues among our astronaut crews. While it would be distracting, if not implausible, for one of us to try to seek even five minutes of time to talk with an astronaut aboard the ISS, distracting noises frequently interrupt their activities and mission, through speech interference, disruptions of mental concentration, and other concerns. A special complication exists aboard the ISS when verbal communication takes place between Russian, American and other crewmembers who have different native languages (and also lose their speechreading cues by rotating their orientations180 degrees while weightless!).

Noise May Have Unknown Interactions With Environmental Factors

The working environment of the ISS includes factors that have been demonstrated to have potentiating effects on noise exposures, such as vibration, ototoxic agents (like carbon monoxide), and physical exercise. The effects of their presence in long-duration flight are not as clear-cut as we'd desire but certainly warrant consideration when reviewing potential risks and implications of threshold shifts seen among noise-exposed personnel.

Conflicts Can Occur Among Those Responsible For Hearing Conservation

Similar to ground-based programs, the ISS HCP has experienced conflicting approaches to resolution of noise problems. Conflicts can occur between key organizations that are responsible for hearing conservation, personified perhaps by classic (and generalized) responses of safety personnel, who may say, "It's not safe until it's proven safe (so wear personal protection)," and operations, whose personnel may contend, "It's safe until shown to be a hazard."

CONCLUSION

In addition to protecting astronauts from hearing loss and other health problems, NASA's approach to noise control is essential to safeguarding data quality and mission effectiveness, especially as the duration and frequency of spaceflights increase. The unique atmosphere of the ISS presents an extraordinary opportunity to adapt and employ hearing conservation practices that have become fundamental to ground-based hearing conservationists. Conversely, the principles used in these "high-level" hearing conservation efforts may renew our focus and success in conventional programs as we recognize our capability to adapt to new technologies and requirements on earth, as well.

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