NASA-STD-3001 Technical Brief

Acoustics

OCHMO-TB-035
Rev C

Relevant Technical Requirements

NASA-STD-3001 Volume 2, Rev D

[V2 6073] Launch, Entry, and Abort Noise Exposure Limits
[V2 6074] Ceiling Limit for Launch and Entry
[V2 6075] Ceiling Limit for Launch Abort
[V2 6076] Launch, Entry, and Abort Impulse Noise Limits
[V2 6077] Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort
[V2 6078] Continuous Noise Limits
[V2 6079] Crew Sleep Continuous Noise Limits
[V2 6080] Intermittent Noise Limits
[V2 6081] Alarm Maximum Sound Level Limit
[V2 6082] Annoyance Noise Limits for Crew Sleep
[V2 6083] Impulse Noise Limit
[V2 6084] Narrow-Band Noise Limits
[V2 6085] Infrasonic Sound Pressure Limits
[V2 6087] Acoustic Monitoring
[V2 6088] Individual Noise Exposure Monitoring
[V2 6106] Noise Limit for Personal Audio Devices
[V2 6115] 24-Hour Noise Exposure Limits

Executive Summary

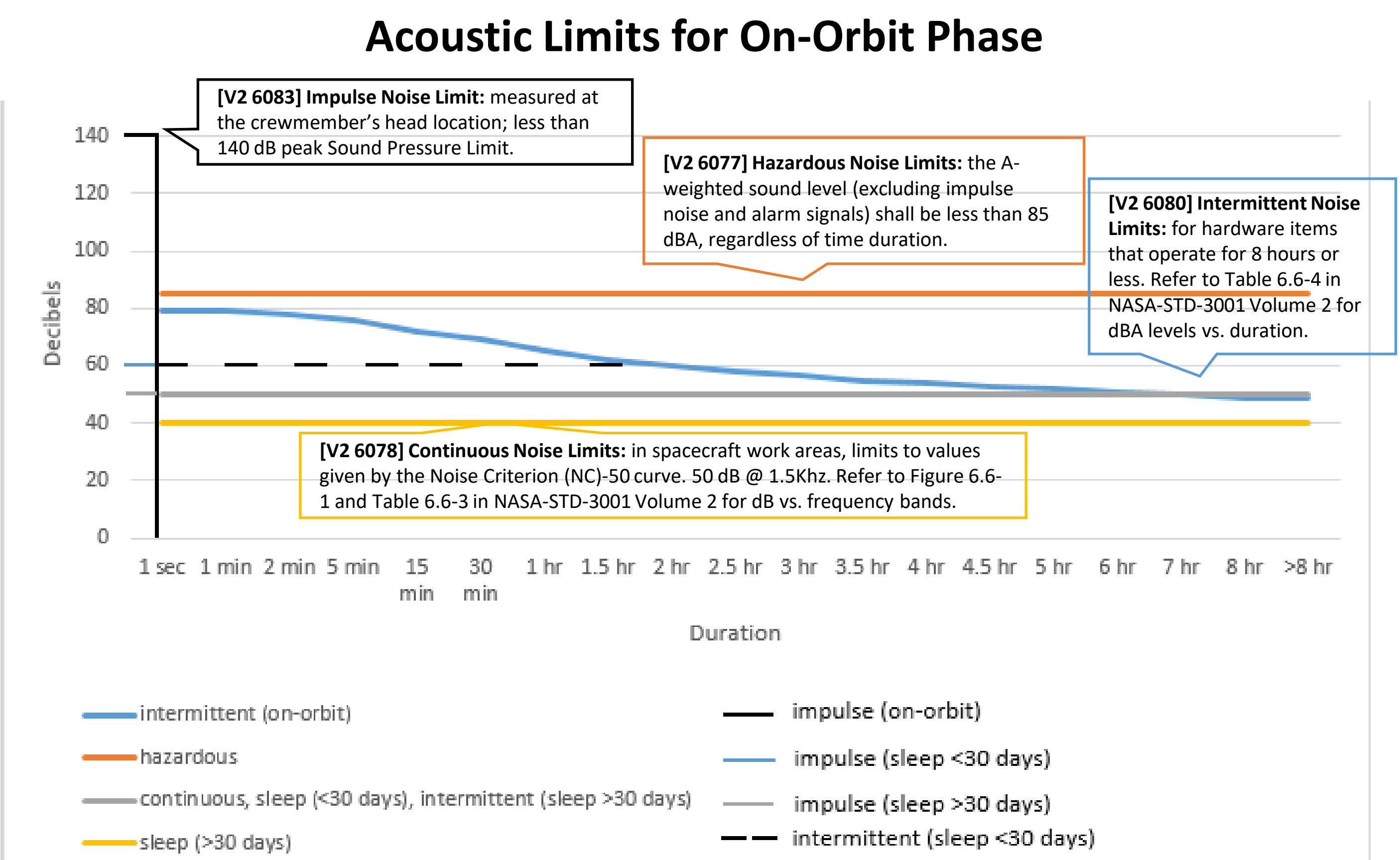
The NASA-STD-3001 Volume 2 acoustic standards ensure an acceptable acoustic environment to preclude noise-related hearing loss, preclude interference with communications, and support human performance. The standards are organized by mission phase due to the unique differences in noise levels and purposes of the standards. The launch, entry, and landing phases generate a great amount of noise caused by the combustion process in the rocket engines, engine jet-plume mixing, unsteady aerodynamic boundary-layer pressures, and fluctuating shockwaves. These phases also generate significant levels of infrasonic and ultrasonic acoustic energy. This short-term noise exposure normally does not exceed 5 minutes of continuous duration. The main focus of controlling noise during this phase of flight is on protection of crew hearing and preservation of critical communications capability.

During **on-orbit, lunar, or extraterrestrial planetary operations phases** when engines are inactive, the focus shifts from protecting crew hearing to ensuring adequate communications, alarm audibility, crew productivity, and habitability. Therefore, the maximum allowable sound levels are lower than those required for launch and entry.

Background

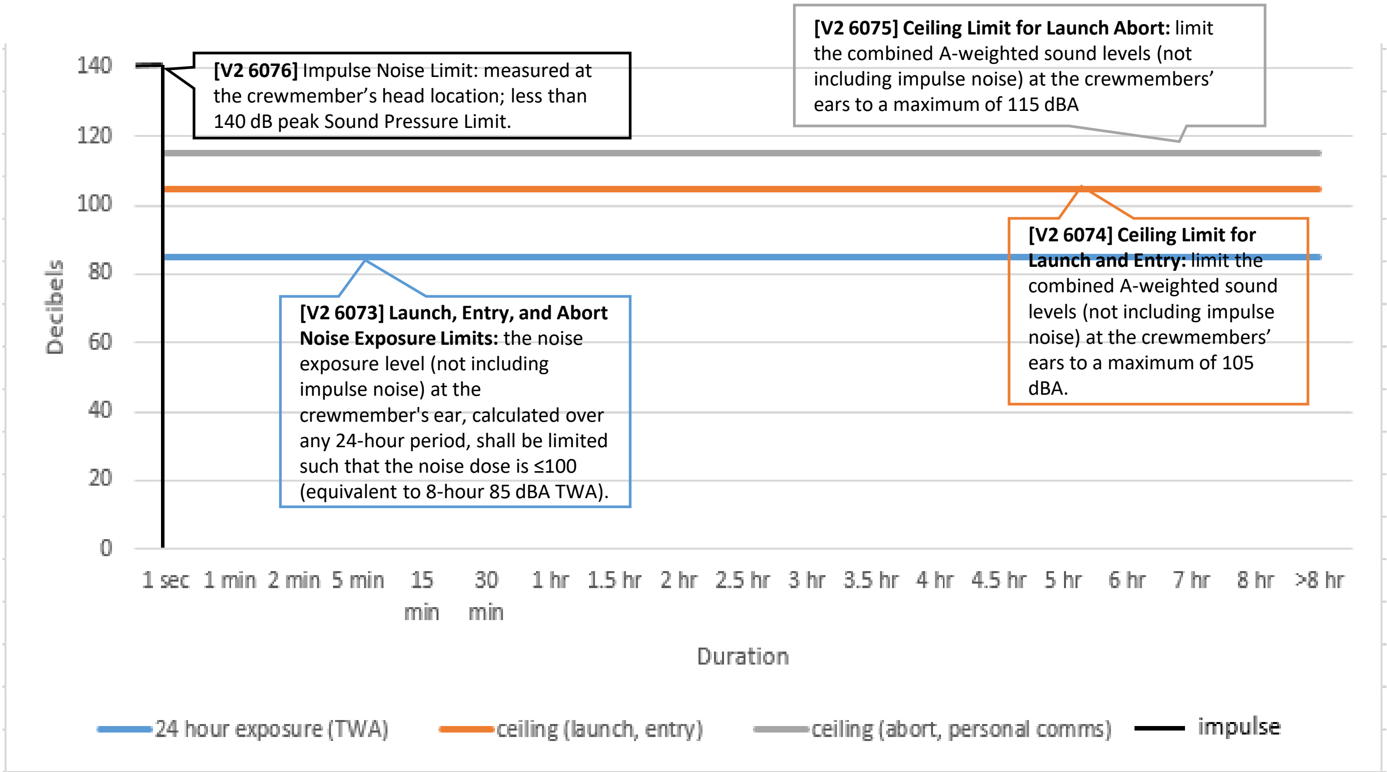
Acoustic levels are measured in decibels – dB

- Frequency and time weighting is applied in the processing stage of sound measurement to make statistical descriptions of sound (e.g., peak or average level) and/or to make the measurements better correspond to human perception.
- Average Predicted risks of hearing damage are based on the noise source's level (typically reported in A-weighted decibels [dBA]) and duration of exposure.
    - **"A-weighting"** - dBA - compensates for the fact that the ear is comparatively less sensitive to lower and very high frequencies. Weighted between 1000 -5000 hertz (Hz).
- **Sound pressure level** uses a logarithmic scale to represent the sound pressure of a sound relative to a reference pressure. The reference sound pressure is typically the threshold of human hearing: 2 x 10^{-5} Pascals (Pa).
- **Impulse** is defined as noises lasting shorter than one second.
- **Intermittent limits** are defined through durations up to 8 hours. For durations longer than 8 hours, the continuous limits take over.



Background

Acoustic Limits for Launch. Ascent, and Descent Phases



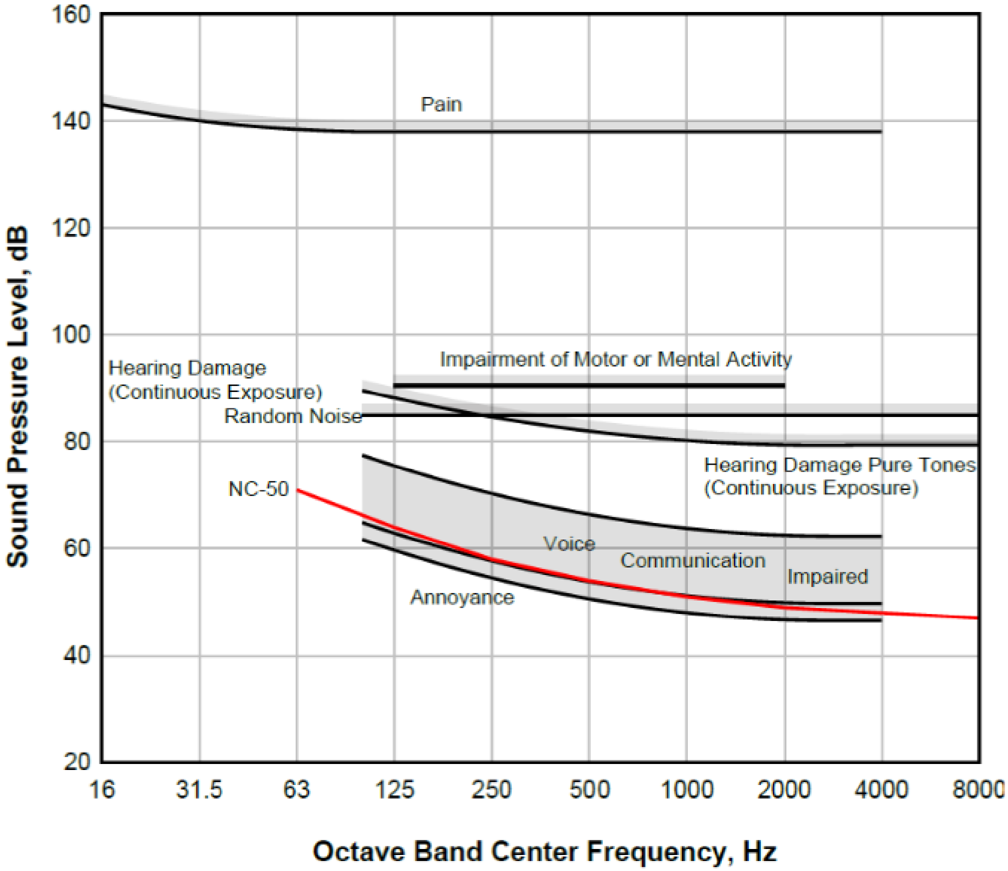
TWA = Time-weighted average

Risks:

Noise exposure is generally considered to affect hearing, but it can also cause other physiological effects (e.g., irritation, headaches, and degradation in sleep and relaxation). Noise can also affect performance of specific activities (e.g., working and speech communications). Even noise that the crew does not perceive as harmful may cause deleterious effects, as the crew may become desensitized to elevated noise levels or not consider the noise to be objectionable (i.e., broad-band, ultrasonic, or infrasonic noise). Because of this insensitivity to sound pressure level changes, it is important to rely on quantitative noise measurements when designing hardware and verifying acoustic characteristics of space vehicles.

Risk of Hearing Loss and Performance Decrements Due to Acoustics Issues in Space

Reference Data



The graph above shows sound limits for various conditions across audible frequencies. Note that limits at low frequencies are higher than those at high frequencies, since the human ear is more sensitive to high frequencies. The NC-50 curve in particular varies from 70 dB at 63Hz to 45 dB at 8 kHz.

Sound levels in the Spacelab Module, a research module located in the Shuttle's cargo bay during STS-40, were measured to be 68 dBA, on a daily average basis, but rose on some days to be as high as 75.5 dBA and up to 84 dBA during ergometer operations (*Goodman, 1991b*). As a result, serious problems with communications, both with the ground and between crewmembers, were experienced. Communications capability within the Spacelab had become obscured by the high ambient noise levels of the experiment hardware, and the crew had to move into the airlock (away from the experiments they were operating) to communicate. Noise levels in the Orbiter Crew Module during STS-40 also were high, reaching daily averages as high as 71 to 73 dBA compared to 73.5 to 75.5 dBA in Spacelab. The crew was very irritated during operations and sleep periods, and reported headaches due to the high noise levels experienced (*Goodman, 1991a*). This is an example of a mission of short duration (less than 30 days) in which high noise levels became a problem because of the resulting poor communications and habitability.

Source: NASA/SP-2015-624 Acoustics and Noise Control in Space Crew Compartments

Application

Monitoring

From International Space Station—A Status Report:

"Acoustic monitoring is an important part of the noise control process on ISS, providing critical data for trend analysis, noise exposure analysis, validation of acoustic analysis and predictions, and to provide strong evidence for ensuring crew health and safety, thus allowing Flight Certification. To this purpose, sound level meter (SLM) measurements and acoustic noise dosimetry are routinely performed."

ISS crewmember performs Sound Level Meter (SLM) Operations to measure the acoustic environment in the ISS.

Design Guidance

Examples of design choices to mitigate noise exposure include:

- Low-noise fans
- Isolating vibrating equipment and components from crewmembers
- Cushioning loud equipment and components*
- Noise-dampening blankets and baffles*

*these materials are soft and porous, so special considerations must be taken for cleanliness and crew health concerns

Additional Information

- Regular maintenance of equipment and components helps reduce noise caused by off-nominal performance.
- Hearing protection (earplugs, earmuffs, etc.) cannot be used to satisfy the requirements, as they pose a risk to crew comfort, health, performance, and communication.

An acoustic engineer validates the Multi-Purpose Crew Vehicle Command Module Volumetric Acoustic Mock-up.

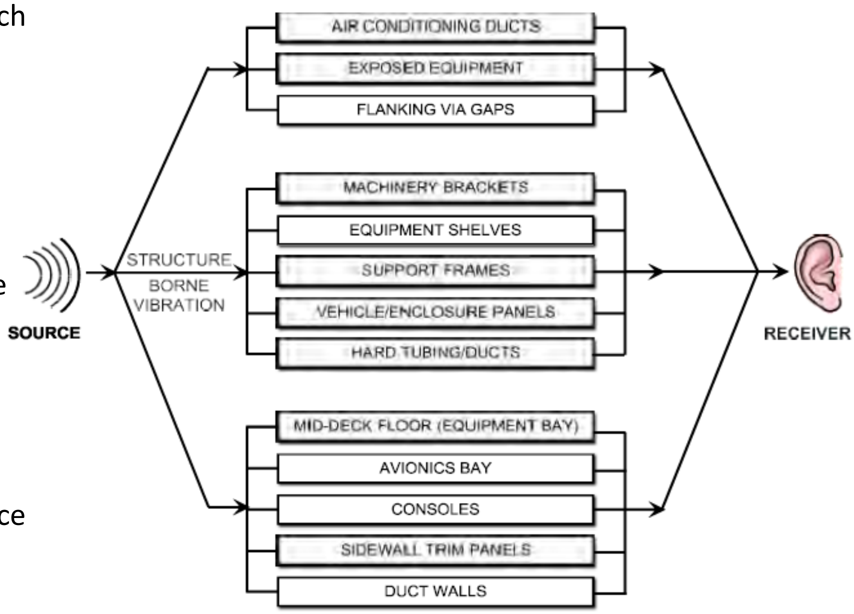
Application

Noise Control Design

The noise control plan defines the approach to be used, and the efforts needed to control noise at the source, path, and receiver. A good approach would be to identify all continuous noise sources; determine the source to receiver paths; estimate the combined systems noise; determine the contribution of each source relative to the total noise; and specify the applicable noise criteria.

During the dynamic stages of spaceflight (takeoff, landing, and abort), there is little that be done to mitigate noise at the source without substantial design changes to the engine. On the ISS, most noise come from fans, which can be primarily mitigated through source control.

Space Shuttle Noise Paths



Sound Path	Source	Control Method
Airborne	Inlets and exhausts of air ducts, exposed equipment, leaks through air passageways/gaps	Using mufflers or silencers for broadband noise, resonators for narrow band noise, active acoustic control systems inside the duct, applications of sound-absorbing materials in the duct lining, and materials to seal the gaps or block the noise.
Structure borne	Structural vibrations and the resultant energy transfer at mountings, connections, and from surfaces	Using vibration isolators and active vibration control systems, applications of passive or active damping materials, and decoupling lines to preclude the transfer of vibration.
Enclosure radiation	Radiated from, or transmitted through, structural enclosures, panels, shelves, and other types of closeout materials.	Material changes, the addition of barrier or stiffening materials for transmission, the addition of damping or viscoelastic materials for radiation, addition of absorbent materials inside the enclosure to absorb acoustic energy or use of active structural acoustic control.

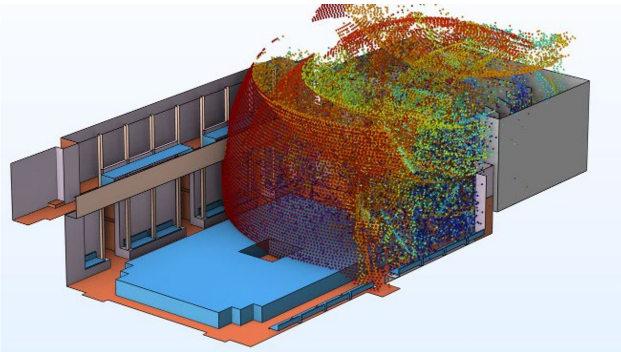
Application

Testing and Verification

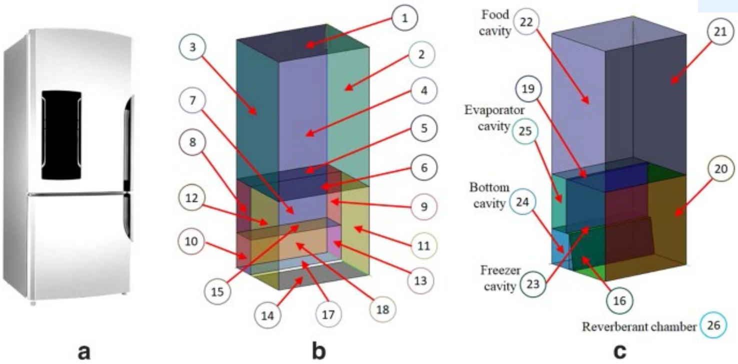
Sound power and directivity measurements of noise sources need to be performed, and the results should be used to determine possible quieting approaches. Simple mock-ups or prototypes can be employed to determine, inexpensively, the effectiveness of mufflers or other noise reduction devices. Testing of the designs and design approaches should be performed as much as possible prior to formal verification testing to minimize unforeseen results, provide time for remedial actions if required, and supply a basis for updating of the analysis to reflect test results. It is important to operate each equipment item individually to determine its noise contribution and frequency content relative to the total noise levels. This provides information for the ranking of the contributing sound sources in selected frequency bands and helps establish priorities for the work to be done.

Computer tools, such acoustic ray tracing and statistical energy analysis can be used in evaluating noise environments.

ESA (European Space Agency) astronaut Samantha Cristoforetti participates in the Acoustic Diagnostics study. The investigation explores whether equipment noise levels and the microgravity environment may create possible adverse effects on astronaut hearing.



Acoustic ray tracing simulation for a music hall



Statistical energy analysis for a refrigerator

Back-Up

Major Changes Between Revisions

Rev B → Rev C

- Updated information to reflect the revisions to language throughout both volumes of NASA-STD-3001.
- Updated/added website links due to new NASA website launch

Rev A → Rev B

- Added information on Noise Control Plans and Testing and Verification.

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the [OCHMO Standards website]

NASA-STD-3001 Volume 2 Revision D

[V2 6073] Launch, Entry, and Abort Noise Exposure Limits During launch, entry, and abort operations, the noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, shall be limited such that the noise dose (D) is ≤100.

[V2 6074] Ceiling Limit for Launch and Entry During launch and entry operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 105 dBA.

[V2 6075] Ceiling Limit for Launch Abort During launch abort operations, the system shall limit the combined A-weighted sound levels (not including impulse noise) at the crewmembers' ears to a maximum of 115 dBA.

[V2 6076] Launch, Entry, and Abort Impulse Noise Limits During launch, entry, and abort operations, impulse noise measured at the crewmember's ear location shall be limited to less than 140 dB peak SPL.

[V2 6077] Hazardous Noise Limits for All Phases Except Launch, Entry, and Abort For off-nominal operations, broadcast communications, depressurization valves, and maintenance activities, the A-weighted sound level (excluding impulse noise and alarm signals) shall be less than 85 dBA, regardless of time duration; except in the case of depressurization valves, the noise attenuation effectiveness of hearing protection or communications headsets may not be used to satisfy this requirement.

[V2 6078] Continuous Noise Limits In spacecraft work areas, where good voice communications and habitability are required, SPLs of continuous noise (not including impulse or intermittent noise sources) shall be limited to the values given by the Noise Criterion (NC)-50 curve in Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa; hearing protection cannot be used to satisfy this requirement.

[V2 6079] Crew Sleep Continuous Noise Limits For missions greater than 30 days, SPLs of continuous noise shall be limited to the values given by the NC-40 curve (see Figure 6.6-1—NC Curves, and Table 6.6-3—Octave Band SPL Limits for Continuous Noise, dB re 20 µPa) in crew quarters and sleep areas. Hearing protection cannot be used to satisfy this requirement.

[V2 6080] Intermittent Noise Limits For hardware items that operate for eight hours or less (i.e., intermittent noise), the maximum noise emissions (not including impulse noise), measured 0.6 m from the loudest hardware surface, shall be determined according to Table 6.6-4—Intermittent Noise A-Weighted SPL and Corresponding Operational Duration Limits for Any 24-hour Period (measured at 0.6 m distance from the source or closest distance to crew head, whichever is less). Hearing protection cannot be used to satisfy this requirement.

[V2 6081] Alarm Maximum Sound Level Limit The maximum alarm signal A-weighted sound level shall be less than 95 dBA at the operating position of the intended receiver.

[V2 6082] Annoyance Noise Limits for Crew Sleep With the exception of communications and alarms, the system shall limit impulse and intermittent noise levels at the crewmember's head location to 10 dB above background noise levels during crew sleep periods. Hearing protection cannot be used to satisfy this requirement.

[V2 6083] Impulse Noise Limit The system shall limit impulse noise measured at the crewmember's head location to less than 140 dB peak SPL during all mission phases except launch and entry. Hearing protection cannot be used to satisfy this requirement.

Referenced Technical Requirements

View the current versions of NASA-STD-3001 Volume 1 & Volume 2 on the [OCHMO Standards website]

NASA-STD-3001 Volume 2 Revision D

[V2 6084] Narrow-Band Noise Limits The maximum SPL of narrow-band noise components and tones shall be limited to at least 10 dB less than the broadband SPL of the octave band that contains the component or tone.

[V2 6085] Infrasonic Sound Pressure Limits Infrasonic SPLs, including frequencies from 1 to 20 Hz but not including impulse noise, shall be limited to less than 150 dB at the crewmember's head location. Hearing protection cannot be used to satisfy this requirement.

[V2 6087] Acoustic Monitoring Broadband and frequency-dependent SPLs shall be monitored and quantified as needed for crew health and safety.

[V2 6088] Individual Noise Exposure Monitoring Noise exposure levels shall be monitored and quantified for each crewmember as needed for crew health and safety.

[V2 6106] Noise Limit for Personal Audio Devices The system shall limit the maximum A-weighted sound level at the crewmember's ear created by a personal audio device to 115 dBA or less.

[V2 6115] 24-Hour Noise Exposure Limits The noise exposure level (not including impulse noise) at the crewmember's ear, calculated over any 24-hour period, except during launch, entry, and abort operations, shall be limited such that the noise dose (D) is ≤100.

All referenced tables and figures are available in NASA-STD-3001 Volume 2 Revision D.

Reference List

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2. Allen, C. (1998). International Space Station Acoustics – A Status Report. *Inter-Noise and Noise-Con Congress and Conference Proceedings, InterNoise 18*, pages 994 - 1998, Chicago, IL, pp. 1319-1334(16).
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6. Christopher, B. (2022). Validating an Acoustic Ray Tracing Simulation of a Chamber Music Hall. *COMSOL Blog*. Retrieved from: https://www.comsol.com/blogs/validating-an-acoustic-ray-tracing-simulation-of-a-chamber-music-hall/