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International Space Station Acoustics – A Status Report

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It is important to control acoustic noise aboard the International Space Station (ISS) to provide a satisfactory environment for voice communications, alarm audibility, and restful sleep, and to minimize the risk for hearing loss. 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 analyses and predictions, and to provide strong evidence for ensuring crew health and safety, thus allowing Flight Certification. And since the primary noise sources on ISS include the environmental control and life support system's air revitalization system (fans and airflow) and active thermal control system (pumps and water flow), acoustic monitoring will indicate changes in hardware noise emissions that may indicate system degradation or performance issues. This paper provides the current acoustic levels in the ISS modules and sleep stations, and is an update to the status presented in 2018. Since this last status report, noise levels have remained consistent, but issues with stalled fan noise and unexplained low frequency spectral peaks have caused some exceedances to requirements. Noise levels in the Russian Segment have either remained consistent or have been reduced slightly, except for the new Multipurpose Laboratory Module, which has some significant noise exceedances.

Nomenclature

dB	=	decibel, unit of sound pressure level when referenced to 20μPa
dBA	=	A-weighted decibel; also used in graphs to indicate A-weighted Overall Sound Pressure Level
NC	=	indicates use of the Noise Criterion family of curves
OASPL	=	Overall Sound Pressure Level denotes SPL including energy over the audible frequency range
Sound Level	=	OASPL when A-weighted, with units of dBA
SIL(4)	=	Speech Interference Level, arithmetic average of 500, 1000, 2000, and 4000 Hz Octave Band SPLs
SPL	=	Sound Pressure Level over a specified frequency range, e.g. octave band, 1/3 octave band

I. Introduction

THE International Space Station (ISS) is home, office, and laboratory for several astronauts and cosmonauts for time periods of six months to a year. And while the crew lives and works aboard ISS, it is important that the acoustic environment allows adequate voice communications and alarm audibility, is conducive to concentration on tasks, provides for restful sleep, and reduces the risks for temporary and permanent hearing loss. However, in order to provide required life support (air and water) and thermal control for the crew and the many experiments, hundreds of noise sources, e.g. fans and pumps, along with corresponding air and water flows, are required and are present within the confined ISS environment in close proximity to the crew. These competing necessities create a challenging environmental acoustic problem to overcome and manage.

In order to control acoustic levels on ISS, the Acoustics System, i.e. all noise sources, controls, remediation, and monitoring, is managed by the Johnson Space Center (JSC) Acoustics Office along with other teams including the ISS Acoustics Working Group (AWG) and Multilateral Medical Operations Panel (MMOP) Acoustics Sub-working Group in conjunction with the system teams which own the noise producing hardware, such as the Environmental Control and Life Support System (ECLSS) and the Active Thermal Control System (ATCS). The AWG is an advisory group comprised of NASA representatives from the Acoustics Office, Space Medicine, Crew Office, ISS Program Office, Safety, and others. The MMOP Acoustics Subgroup is comprised of the acoustics engineering and audiology

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experts from the various international partners including American, Russian, European, Japanese, and Canadian members.

The methods and practices used to control the ISS acoustic environment include a strong set of requirements and verification requirements, with noise control implemented during the design and development of the hardware, combined with predictive analyses, testing, on-orbit acoustic monitoring, and if required, on-orbit mitigation of high noise problems. Goodman[1] describes in further detail some of the issues concerning control of noise on ISS, including the importance of having Program and Project Management support for controlling noise levels, which is critical.

Allen and Goodman[2] describe the process of ensuring safety of flight regarding acoustic levels on ISS, including the Certification of Flight Readiness (CoFR) process. Examples of hardware noise control are discussed by Grosveld et al.,[3] Phillips and Tang,[4] and by Goodman and Grosveld[5] on implementation of noise control for human spaceflight vehicles in general.

In 2011, Allen and Denham[6] provided an update on the status of acoustic levels on ISS. Acoustic levels in the, then recently added, European Columbus Operational Facility (COF), Japanese Experiment module (JEM), Japanese Logistics Pressurized module (JLP), Node 2, and Node 3 modules were shown and discussed, as were the low acoustic levels in the new Crew Quarters. The U.S. Segment was shown to have met requirements in all modules except in Node 3. Levels in the Russian Segment were also shown, including sound level reductions in the Service Module (SM), where the crew spend much of their time and in the Mini-Research Module #1 (MRM1), due to quiet fan installations.

In 2015, Allen[7] provided an update on the status of acoustic levels on ISS, including a discussion of the change in sound pressure level requirements for laboratory modules, introducing a modified Noise Criterion (NC) curve, NC~52. Then, as with the 2011 update, acoustic levels in the U.S. Segment and the Russian Segment modules were discussed. Levels in the U.S. Segment were shown to still meet requirements, except for Node 3. And, continued improvement in Russian Segment acoustic levels were shown as the result of many quiet-design fan installations. Two on-orbit acoustic issues were also discussed, including high levels from the T2 treadmill and a Waste and Hygiene Compartment (WHC) noise problem.

In 2018, Allen[8] provided a further update on the status of acoustic levels on ISS, including a discussion of noise remediation work performed in Node 3 to address the continuous noise level exceedances in Node 3 and to reduce the high sound levels of the T2 treadmill. The resulting Node 3 noise levels were presented, and showed that the noise mitigation efforts reduced Node 3 continuous noise levels significantly. These efforts included installation of new acoustically treated rack-front doors for the Water Reclaimation System rack #2 (WRS2). Acoustic blankets were installed to reduce the noise levels of the T2 treadmill, but also acted to reduce the Node 3 continuous noise levels. As a result, Node 3 was shown to be close to meeting its NC-52 continuous noise requirement. T2 noise levels, at the runner's head-location, were also reduced by the acoustic blankets by 2 dB, so that the hazard level is now not exceeded at the highest treadspeed.

The purpose of the current paper is to provide an updated status for 2024, covering up to ISS Increment 70. As with the 2018 update, acoustic levels in the U.S. Segment and the Russian Segment modules will be discussed. Levels in the U.S. Segment will be shown to mostly meet requirements, while acoustic levels in the Russian Segment will be shown to have remained consistent with the 2018 levels, with the addition of the Multipurpose Laboratory Module.

The sound pressure level (SPL) data provided in this paper were measured by the ISS on-orbit crew, using a Svantek SV102A+. The SV102A+ is an acoustic dosimeter as well as a sound level meter (SLM), and so is referred to as the ISS Acoustic Monitor. Note that all SPL measurements using the SV102A+ are of Type 1 measurement accuracy.

Crew-worn and fixed-location acoustic dosimeter measurements are described by Limardo et al.,[9] along with explanations of flight rules that govern when hearing protection use is recommended or required aboard ISS.[10]

II. U. S. Segment Acoustic Levels

Acoustic levels in the Node 1 and Airlock have consistently met requirements since 2003. The latest levels in these modules are shown in Fig. 1. The Airlock levels shown were measured on May 11, 2023 and show that the levels are are significantly below the NC-50 module requirement in the Crew Lock, but exceed NC-50 by 2 dB at 500 Hz in the Equipment Lock. This is only a minor exceedance.

The Node 1 levels were acquired on April 8, 2024. The spectrum that is shown in Fig. 1 is a spatial average of four separate measurements that were made at locations along the centerline of the module. Node 1 is shown to be meeting the NC-50 requirement in all frequency bands. However, other recent measurements, not included here, have shown some exceedances. But even with these exceedances, Node 1 is consistently below its approved exception to the NC-50 requirement. This exception was approved in 1998 to allow the 500 Hz and 1000 Hz octave band SPLs to be up to 59 dB and 54 dB, respectively, based on ground-test measurements.

Acoustic levels in the U.S. Lab have remained steady since the 2018 update, except in the aft portion of the lab where increased Pump Package Assembly (PPA) speeds have increased SPLs around the 2000 Hz frequency band. This PPA speed increase was implemented to increase the cooling water available for payloads. Also, the Oxygen Generation System rack was moved into the forward part of the lab and also needs significant cooling water for operatons.

Fig. 2 shows the current U.S. Lab acoustic levels for forward, center, and aft locations as well as the spatial average spectrum of measurements made down the centerline of the module. The result is that the U. S. Lab average SPLs slightly exceed the NC~52 requirement, with a 1.1 dB exceedance in the 1000 Hz octave band, and a 0.9 dB exceedance in the 2000 Hz band. During this period, the U.S. Lab average speech interference level, SIL(4),[11] was approximately 53 dB, and the average sound level was approximately 60 dBA.

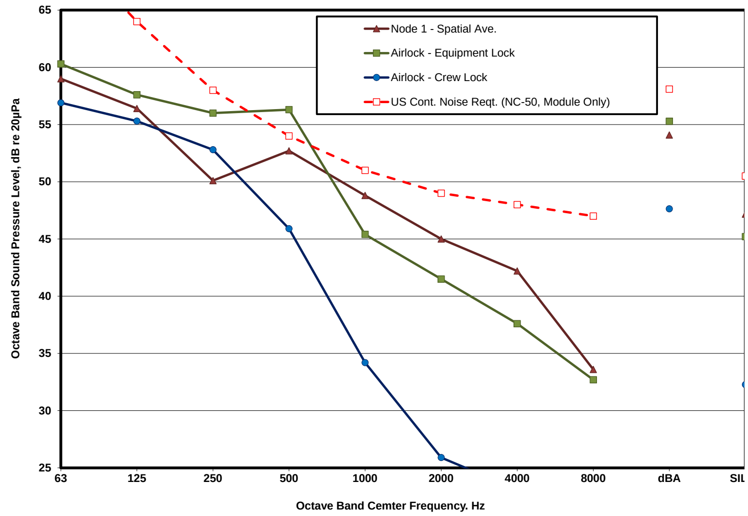

Figure 1. Node 1 and Airlock acoustic levels.

Sound levels in the other U.S. Segment laboratories, the COF and JEM, remain below requirements, except when inter-module ventilation (IMV) fans become clogged with dust and are stalled.[6] Fig. 3 shows the COF and JEM spatial average spectral levels along with those of JLP, Cupola, and the Permanent Multipurpose Module (PMM). Note that the COF and JEM averages are shown in comparison to the NC-50 vehicle only requirement, whereas they are required to meet the NC~52 vehicle plus payloads requirement, shown in Fig. 2. The COF is just above NC-50 and meets NC~52. The JEM acoustic levels shown in Fig. 3 are below NC-50 and NC~52, meeting requirements. However, other measurements made since 2018 in the JEM have indicated a stalled IMV fan from time-to-time, producing elevated noise levels. In general the acoustic environments in these modules have remained consistently below their continuous noise requirements, with the exception of the stalled fan noise in the JEM.

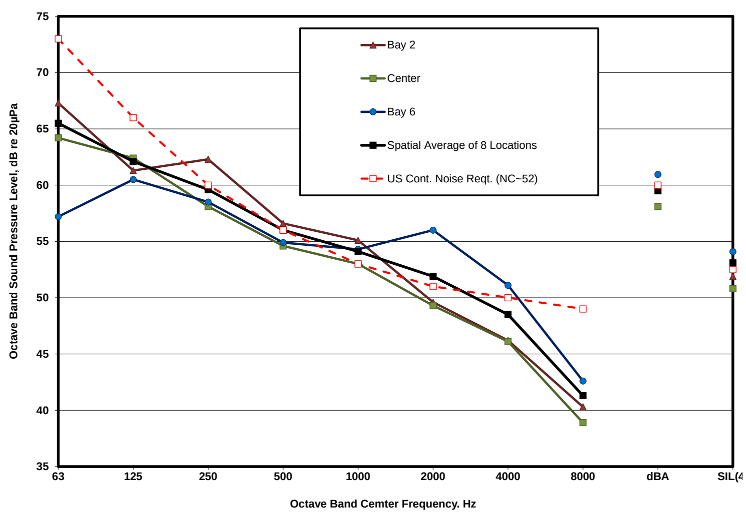

Figure 2. U.S. Lab acoustic levels (January 3, 2024).

The COF acoustic levels shown in Fig. 3 were measured on July 6, 2023, and are a spatial average of 5 measurement locations. When compared to the corresponding levels in Ref. 8, the current data show a slight decrease from NC-51.1 to NC-50.8, with the SIL increasing from 45.9 dB to 49.2 dB, and the sound level also increasing from 54.1 dBA to 56.8 dBA.

The JEM levels shown in Fig. 3 were measured on July 1, 2022 and are a spatial average of seven measurement locations spanning the module. When compared to the corresponding levels in reference 8, the current data show increases from NC-48.1 to NC-53.5, because of a peak in the 63 Hz octave band and slight increases from a SIL of 47.5 dB to 47.6 dB, and a sound level from 54.1 dBA to 55.6 dBA.

The JLP and PMM are basically stowage closets and remain at low levels. The JLP NC, SIL and sound levels are NC-46.8, 42.3 dB, and 49.7 dBA, respectively. The PMM NC, SIL and sound levels are NC-41.8, 37.9 dB, and 46.2 dBA, respectively. Both of these modules are well below their NC-50 requirement, as shown in Fig. 3.

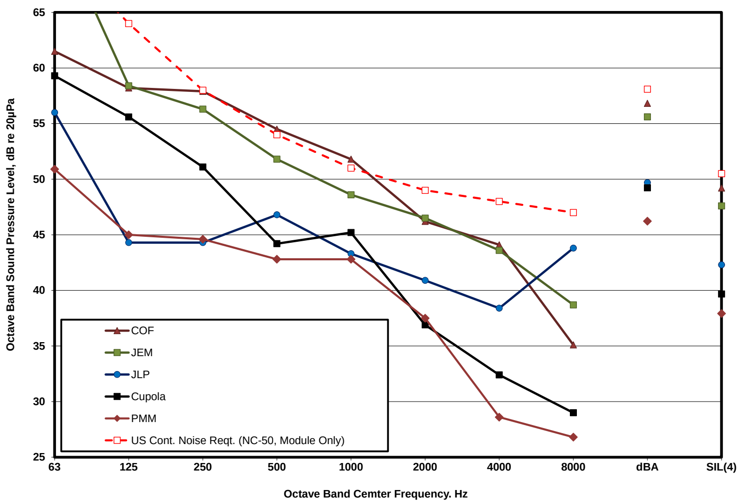

Figure 3. Acoustic levels in COF, JEM, JLP, Cupola, and PMM.

The Cupola, measured on April 8, 2024, is shown in Fig. 3 to meet the NC-50 requirement with NC, SIL and sound levels of NC-44.2, 39.7 dB, and 49.2 dBA, respectively.

Acoustic levels in Node 2 are shown in Fig. 4. Sound pressure levels at most locations exceed the NC-50 requirement, with spectral peaks in the 500 Hz and 1 kHz octave band may indicate the presence of a stalled IMV fan. The spatial average metrics (of the four central measurement locations, 2-5) are NC-53.6, SIL of 47.4 dB, and sound level of 57.5 dBA. Levels in Node 2 have exceeded NC-50 since April 2015. It is thought that IMV fan stalling has been the cause of these exceedances as there are several IMV fans that have a history of stalling in Node 2, and any one of these being stalled raises the noise levels. See reference 6 for more details on IMV fan stalling noise.

The acoustic levels inside the four Node 2 Crew Quarters (CQs) are shown in Fig. 5. These are the levels with the CQ fans on the high setting. The levels are generally lower at the two other fan speeds. The design requirement for the interior of the CQs is NC-40, and levels at the lowest fan speed are thought to be below or close to this value (not shown). Refer to the inset in Fig. 4 for the CQ locations, 7-10, within Node 2.

Fig. 5 shows that the sound levels in the CQs range from 49 to 54 dBA with their fans operating on high speed. Sound levels of 50 dBA or below have been shown to be an acceptable level for restful sleep over a short-duration[12] and is the level required in the ISS Flight Rule B13-152, Noise Constraints Flight Rule for ISS sleep stations. A sound level of 62 dBA is considered, in Flight Rule B13-152,[10] to provide adequate hearing rest from the day's noise exposure.[9] The current acoustic metrics inside the Starboard, Port, Overhead (Zenith), and Deck (Nadir) CQs (on high speed setting) are NC-47.6, NC-48.2, NC-52.8, and NC-42.5, respectively, with corresponding sound levels of 51.6 dBA, 51.5 dBA, 53.5 dBA, and 48.5 dBA, respectively.

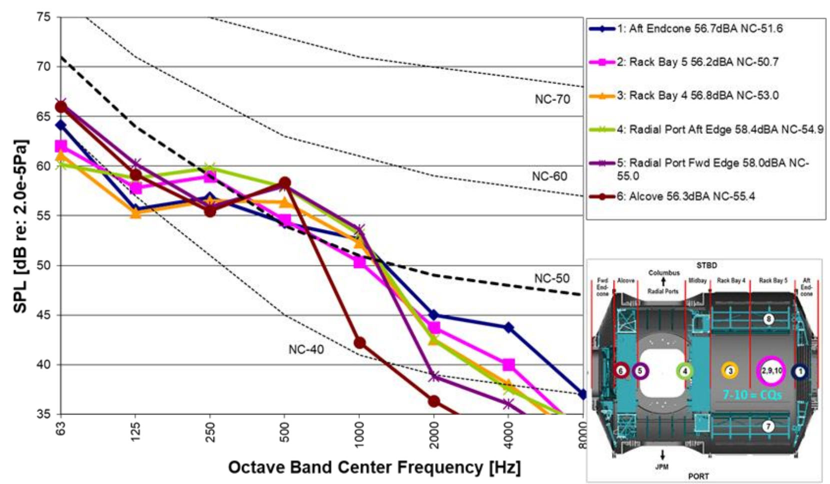

Figure 4. Acoustic levels in Node 2 (October 3, 2023).

Also shown in Fig. 4 are the acoustic levels for the new Crew Alternate Sleep Accommodation (CASA), which can be temporarily assembled in the COF and is used during crew hand-off periods. CASA is very quiet (quietest spot on ISS) at NC-36.6 with a sound level of 43.8 dBA.

The acoustic levels in Node 3 are not shown here for brevity. However, noise measurements made on April 8, 2024 indicate that sound pressure levels in Node 3 meet the requirement of NC-52. When compared to the corresponding levels in Ref. 8, the current Node 3 spatial average data show a decrease in noise from NC-54.6 to NC-50.5, with the SIL decreasing from 49.7 dB to 47.1 dB, and the sound level also decreasing from 58.9 dBA to 55.9 dBA.

III. Russian Segment Acoustic Levels

In the 2011 ISS acoustics status update, reference 6, the noise controls implemented as part of the Service Module (SM) remedial action plan (RAP) were discussed in detail. These noise controls were added to the air conditioning system (acronym CKB in Russian), carbon dioxide removal system (Vozdukh), and to the ventilation system. The CKB controls included a compressor acoustic wrap, hose lagging, fan acoustic cover, and a new/improved acoustic close-out panel on each of the two CKB units. Vozdukh noise controls included an acoustic form-fitted cover over the micro-compressor and additional acoustic blankets between the micro-compressor and close-out panel. Ventilation system controls included fan vibration isolators and casing wraps on many of the 40+ fans in the SM. Several of these fans were also equipped with inlet and/or outlet mufflers. Refer to reference 6 for details, including photographs and discussion of their effectiveness.

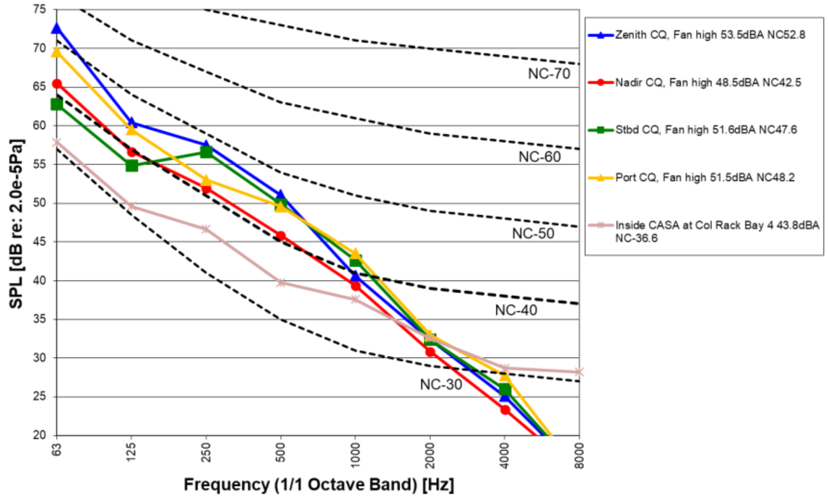

Figure 5. Acoustic levels in the Crew Quarters (October 3, 2023) and in Crew Alternate Sleep Accommodation (April 6, 2022).

In addition to these noise controls, reference 6 discusses status on the development of a new quiet-design fan to replace many of the SM and other Russian Segment fans, including the aerodynamic and acoustic performance of the new fan design, which were both vastly improved over the previous fan model. By 2011, only two of these fans had been installed in the Mini-Research Module #1 (MRM1) and noise reductions of this installation were presented.[6]

In the 2015 ISS acoustics status update, reference 7, details of quiet fan installations and their noise reducing effects were discussed in detail. These installations were made in the SM, MRM1, and in the Docking Compartment (DC-1). Significant noise reductions were shown in all of these modules, but especially in the MRM1 and DC-1. See reference 7 for details on these reductions.

Since 2015, quiet fan installations in the Russian Segment have only been planned to occur to replace failed fans. No known failed fan replacements have occurred in this timeframe. Also, no significant noise control efforts have taken place in the Russian Segment, since the 2015 status update. In the following discussion, results of the latest noise survey measurements in the Russian Segment will be presented.

Fig. 6 shows the current, nominal acoustic levels in the large area of the Service Module (SM), measured on July 1, 2022. When compared to the corresponding levels in Ref. 8, the current Service Module spatial average data show that noise levels have remained steady at NC-57.9 and with SIL from 55.7 dB to 55.5 dB, and sound level from 62.9 dBA to 63.0 dBA.

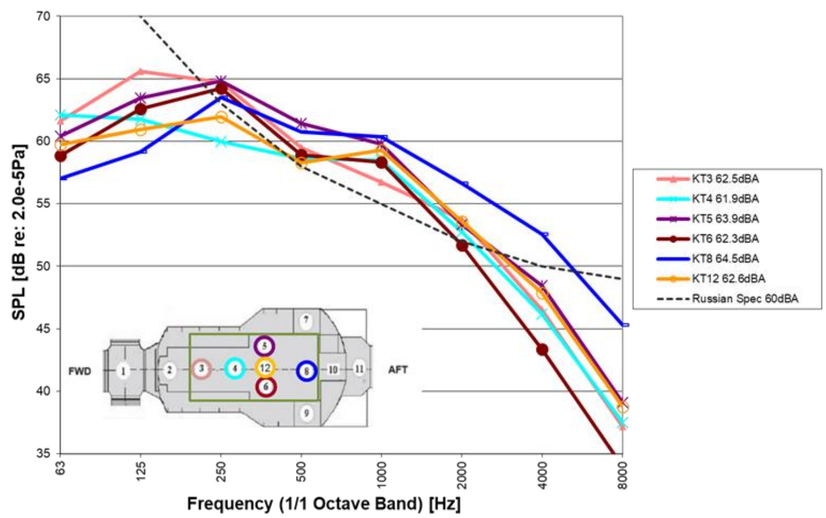

Figure 6. Acoustic levels the Service Module (July 1, 2022).

Fig. 7 shows the current nominal average acoustic levels in the other Russian Segment modules, compared to the Russian Segment continuous noise specification. Average acoustic levels from measurements in the FGB on April 8, 2024 are NC-58.5, SIL of 52.7 dB, and sound level of 61.8 dBA. These values are all significantly lower than the corresponding values given in Ref. 8. Several niose reduction measures have taken place in the FGB, including replacement of dust filter and circulation fans with quiet-design fans. Also, fans that have operated well past their service life have been de-activated (switched to become backup fans) in favor of the previous backup fans with more life left. It is unclear at this time if all of the noise reductions are due to these causes. There are also further noise reduction measures planned for FGB, including replacement of ventilation ductwork that include noise controls that have deteriated.

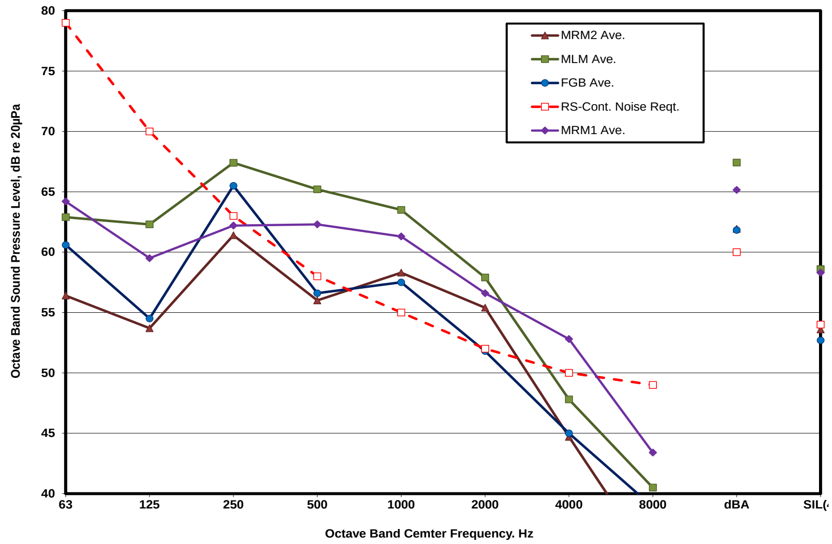

Figure 7. Summary of average acoustic levels in Russian Segment Modules, excluding the SM and NM.

Average acoustic levels measured in the MRM1 on October 3, 2023 are NC-60.3, SIL of 58.3 dB, and sound level of 65.2 dBA, similar in levels compared to the values reported in the 2018 update. Review of the individual measurement location spectra (not shown) indicates a dominant noise source located at the Nadir end of the module (away from all MRM1 noise sources). This source is thought to be the docked Soyuz vehicle.

Average acoustic levels in the MRM2, measured on October 3, 2023, are NC-57.3, SIL of 53.6 dB, and sound level of 61.9 dBA. This NC value is within 1 unit of the value reported in the 2018 update and within 1 dB of the SIL and 2 dBA of the sound level.

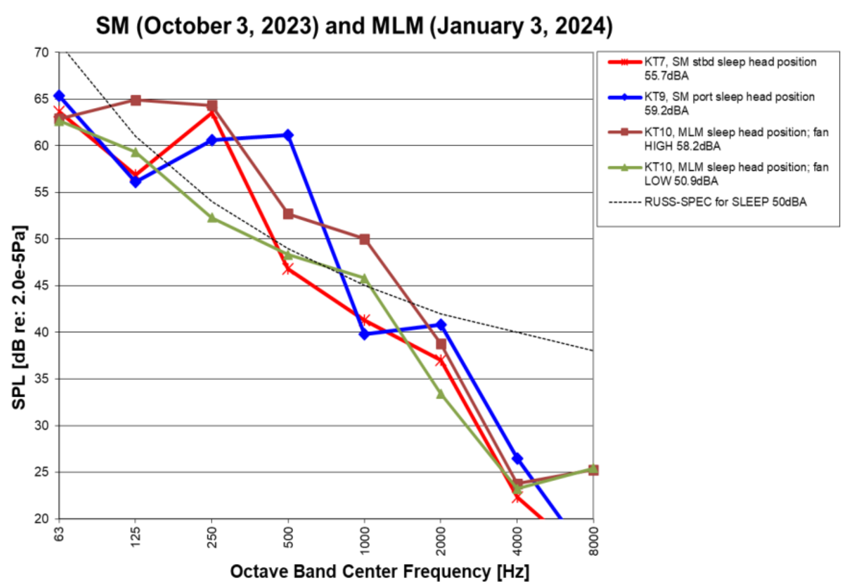

Figure 8. SM Starboard and port kayuta (October 3, 2023) and MLM kayuta (January 3, 2024) sound pressure levels.

The DC-1 was removed from the ISS Russian Segment to make room for the new Russian Node Module (NM) and Multipurpose Laboratory Module (MLM). The quiet fan that was installed in the DC-1 was removed and saved to be used as a spare prior to DC-1's disposal.

The Russian NM acoustic levels were measured on October 3, 2023 to be NC-46, with SIL of 42.2 dB and sound level of 50.5 dBA. The NM contains only one quiet fan, and as a result is very quiet, meeting the Russian Segment continuous noise requirement.

The new MLM module was equipped with quiet fans. However, noisy cooling pumps are causing high noise levels in the module. These pumps could not be remediated prior to launch. Efforts are currently underway to design quieter pumps to replace the noisy ones while on-orbit. Spatial average acoustic levels measured on January 3, 2024 in the MLM are NC-62.5 with SIL of 58.6 and sound level of 67.4 dBA. The MLM operates under a Safety Non-compliance Report for these noise levels. Remediation is in work.

The Russian Segment contains three sleep stations, i.e. kayutas, with one new kayuta located in the MLM. Recent sound pressure levels in the kayutas are shown in Fig. 8. Sound levels of the SM starboard and port kayutas are 55.7 dBA and 59.2 dBA, respectively, and are elevated compared to previous measurements. The MLM kayuta levels are shown for two fan speeds, high and low, with resulting sound levels of 58.2 dBA and 59 dBA. As discussed above, the Russian sleep requirement of 50 dBA is seen to protect for restful sleep, while a sound level of 62 dBA will provide adequate hearing rest from the day's noise exposure.

IV. Conclusions

Since 2018, acoustic levels in the ISS U.S. Segment have remained consistent in meeting their respective continuous noise requirements, with the exception of the JEM and Node 2 when the stalling of different IMV fans is causing noise levels to exceed requirements some of the time. Node 3 levels have decreased slightly, and Node 3 is now meeting its NC-52 continuous noise requirement. Noise levels in the U.S. Crew Quarters are slightly elevated but are still within the acceptable range for the crew's recovery from daily noise exposure. The new CASA provides a very quiet place to sleep when needed.

In the Russian Segment, since 2018, acoustic levels of the legacy modules have remained consistent. The Service Module noise levels have been steady, and currently meet the Remedial Action Plan goal of 63 dBA. FGB noise levels are reduced, and efforts to further reduce levels is in work. The new NM is meeting acoustic requirements, but the new MLM module's acoustic environment is well above noise requirements. Remediation for the MLM noise levels is currently in work.

Acknowledgments

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