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Noise Emission Testing Requirements For Spaceflight Hardware

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1. INTRODUCTION

Spaceflight hardware intended for use on the International Space Station or Space Shuttle must be tested for noise emission in accordance with NASA directives to meet stringent requirements.

NASA directives covering verification of acoustic noise provide explicit testing requirements and guidance regarding verification of noise emission. They also allow considerable latitude for making measurements in informal spaces. While it's true that all acoustical test environments influence measured results to some extent, informal test spaces are characterized by the fact that this influence is unknown and/or undocumented. The bias is generally towards higher results and can be on the order of several dB in informal spaces. The potential exists that developers, acting on the basis of biased data, may be led to invest a great deal more effort on noise control than is truly necessary.

This paper summarizes the explicit testing requirements and provides methods for assessing the potential upward bias on measurement results introduced by a test environment.

2. CRITERIA DOCUMENTS

An NC-50 criterion has been selected for integrated ISS modules, based upon several considerations: safety, productivity, annoyance, and sleep interference. Noise in the module is the sum of contributions from many sources, which have been sub-allocated by NASA to the level of integrated and non-integrated racks.

Noise emission criteria for Space Shuttle (SSP) and International Space Station (ISS) payloads are contained in NASA SSP 57000, Revision E[1], PIRN-57000-NA-0208[2], and JSC 23822[3].

Continuous noise is defined as noise from operations having a daily duration greater than 8 hours. For continuous noise under normal operating conditions, sound pressure level measured at the point of highest A-weighted sound pressure level 600 mm from the equipment shall not exceed NC-40, which octave band values are given in Table 1.

Intermittent noise is defined as noise from operations having a daily duration less than or equal to 8 hours. The maximum A-weighted sound pressure levels given in Table 2 shall not be exceeded when measured at the point of highest A-weighted sound pressure level 600 mm from the equipment.

3. SUMMARY OF REQUIRED METHODS FOR NOISE EMISSION TESTING

Measurement procedures are described in NASA SSP 57010B, Appendix D[4] and JSC 23822, Appendix A[5]. Considerable latitude is given in defining acceptable test environments and procedures in order to encourage testing throughout the equipment development program. Thus the documents often contain less specificity than might be expected from ANSI or ISO test standards. The requirements for test rooms, equipment and measurement procedures are summarized below. The reader should be aware that interaction with the ISS Acoustics Working Group is required to review test plans and measurement data; these requirements are not covered in this paper.

A large room is required with a minimum dimension of 4 meters, although 6 meters is preferred. Large acoustically-reflective articles (e.g., bookcases) are to be placed at least 3 meters from the test article or removed altogether. Inner room surfaces should be “as acoustically absorbent as possible”.

Ambient sound pressure levels should be low. Test article sound pressure levels should be 3 dB greater, and ideally 15 dB greater, than the ambient in each octave band.

The test article is placed on a small table or stand about one meter high near (but not at) the center of the room, in an orientation not parallel with the walls. Ancillary support equipment should be located in such a way that its sound pressure levels are 10 dB less than the test article in each octave band of interest.

A precision (Type 1) sound level meter and octave band filter set are required. Field calibration is required before and after noise measurements; laboratory calibration is required within the last 12 months.

The test article is to be operated in such a manner that it produces the maximum noise that will occur on orbit. The location of the highest A-weighted sound pressure level measured 0.6 m from the test article is determined using a manual sweep. If the level does not reach 37 dBA, the test article is exempt from further testing. If the maximum noise mode is not known beforehand, candidate modes are tried and the mode with the highest A-weighted level is selected.

If the A-weighted sound pressure level is greater than 37 dBA at any point during operation and if operation is classified as continuous, octave band sound pressure level measurements are performed with the microphone stationary at the noisiest location identified above. Octave bands are to be reported with linear (not A-weighted) response.

Measurements are reported with the test article off and with the equipment input sensitivity ranges unchanged in order to document the influence of ambient noise on the results.

JSC 28322 Appendix A[5] refers to ambient-corrected sound pressure levels. SSP 57010B, Appendix D[4] does not. In either case if the test article sound does not exceed the test room ambient and the ambient meets the criterion, the test article is assumed to meet the criterion as well.

Current specifications require sound power level testing per ANSI or ISO standards if the test article does not meet the stated criterion. There are indications that the requirement for sound power testing will be lifted in the near future.

4. CANDIDATE TEST SITES

NASA directives are designed to give equipment developers maximum latitude in selecting test facilities in order to help control costs and encourage testing throughout development. It is assumed that the developer may select an informal environment close at hand rather than a formal acoustical testing lab for at least some of the noise emission testing. Informal environments are typically characterized by greater levels of ambient noise and acoustic reflections than expected in a dedicated acoustic test chamber. The acoustic reflections determine the degree of upward bias in measured results. The ambient noise determines the lowest sound pressure levels that can be measured with sufficient accuracy.

The chief disadvantage of formal acoustical facilities to most developers is that they cost money to use, are located offsite, and may not be immediately available. Informal test facilities are usually sought within the developer's own offices or nearby in the local area. Given that most developers do not intend to significantly modify spaces with additional sound absorption, it follows that good candidate test environments include spaces that are both large and quiet.

Influence of Acoustic Reflections

Test room bias due to acoustic reflections can be assumed to be equal to the environmental correction factor K_2 used in engineering grade sound power standards such as ISO 3744[6]:

$$K_2 = 10 \times \log_{10}\left[1 + 4\left(\frac{S_m}{\sum A_i}\right)\right]$$

where;

S_M = area of measurement surface
A_i = is the sound absorption of i-th room surface, computed as $S_i\alpha_i$, where S_i is the surface area and α_i the sound absorption coefficient of the i-th room surface.

NASA directives do not permit adjustment for acoustic reflections, so it should be expected that this bias will be preserved in the data. Desirable biases are achieved in spaces that are large compared to the measurement surface and have sufficient sound absorption for their size. For reference, K_2 of 2 dB or less is acceptable for engineering grade sound power level determination per ISO 3744, and K_2 of 7 dBA or less is acceptable for survey grade sound power level determination per ISO 3746[7]. Testing in spaces with K_2 > 7 dB should be avoided.

The measurement surface would best be taken as the surface area of the rectangular box (parallelepiped) enclosing the test article above and on all sides with a standoff of 0.6m, and extending down to the floor. Computed biases for various ratios of $\Sigma A_i/S_m$ are given in Figure 1. Note that the sound absorption coefficient varies with frequency for most materials, so that a K_2 value should be computed for each octave band. Values of α can be obtained from a number of reputable sources such as Moulder[8].

Example K_2 computations for two imaginary test rooms follow in Tables 3 and 4. The first is a small conference room with extra sound absorption added to improve its performance: K_2 values range from 3 to 6 dB. The second is a large warehouse with no acoustical treatments whatsoever: K_2 values range in this case from 1 to 4 dB. Given comparable ambient noise conditions, the large untreated warehouse would actually be preferred over the small conference room.

Ambient Noise

Perhaps the most significant shortcoming of informal spaces is excessive and/or dramatically variable ambient noise. Sources of ambient noise include:

- host building: HVAC system fan and grilles, fluorescent light ballasts
- pedestrian traffic: footfalls, door slams, conversation
- work activities: forklifts, punch presses, construction, etc.
- weather: wind, rain, thunder
- exterior traffic: aircraft, automobiles and trucks, railroad, car stereo subwoofers

The directives state that the test article should be capable of producing noise 3 dB greater than the ambient. The combined test article and ambient are therefore expected to be roughly 5 dB above the ambient alone. From this it can be inferred that the maximum permissible ambient is 5 dB below the criterion. Therefore for continuous noise and integrated racks, ambient noise less than roughly NC-35 is required.

For individual subrack components, a common sub-allocation criterion is NC-32, which implies a corresponding ambient limit of NC-27. For intermittent noise, ambient levels of 44 dBA to as high as 74 dBA (!) are tolerable depending on the duration of operation.

Although design guidelines for HVAC noise in interior building spaces typically specify levels below NC-35, this goal is not always achieved in practice. A study of ambient noise levels in several carefully screened candidate test spaces at NASA Glenn Research Center[9] reveals that most met NC-35, but only a few met NC-27.

The increase in measured sound pressure level due to ambient noise depends on the difference between the ambient and test article sound pressure levels in each octave band or A-weighted as:

$$\Delta L = 10\log_{10}\left(1 + 10^{0.1(L_{AMB} - L_{TEST})}\right)$$

where:
L_{AMB} is the ambient sound pressure level, and
L_{TEST} is the test article sound pressure level in the absence of ambient noise.

For the minimum 3 dB difference recommended by the specifications, measured levels would be elevated by 1.8 dB. For the ideal 15 dB difference, measured levels would be elevated by only 0.1 dB. Note that JSC 28322 Appendix A appears to permit background level corrections, but SSP 57010B Appendix D does not explicitly mention the correction.

Figure 2 compares the ambient spectra of these spaces with a hemi-anechoic chamber and a 3-meter EMC chamber with RF anechoic wedges.

5. CONCLUSION

A summary of criteria and noise emission testing requirements for ISS and SSP spaceflight hardware has been presented. Methods of evaluating test spaces have also been described.

A rudimentary equation for assessing the bias introduced by acoustic reflections has been presented in order to facilitate comparison of the acoustical performance of candidate test spaces along with example computations. The bias may not be corrected out of data submitted to NASA. Preferred environments are characterized by a combination of large size relative to the test article and acoustically treated surfaces.

A simple equation for assessing the bias introduced by ambient noise has also been presented. This bias may be corrected out of data submitted to NASA under certain circumstances.

NASA Glenn Research Center's Acoustical Testing Laboratory is preparing an in-house model test code as part of its accreditation activities. The intent of the test code is to unify the testing requirements in one document in a format similar to ANSI and ISO standards. This test code will be available to the public upon completion.

6. REFERENCES

[1] *Pressurized Payload Interface Requirements Document*, NASA SSP 57000, Revision E, (National Aeronautics and Space Administration)

[2] *Refine (Relax) Intermittent Noise Limit Durations,* PIRN-57000-NA-0208, (National Aeronautics and Space Administration)

[3] *ISS Acoustic requirements and testing document for ISS non-integrated equipment*, JSC 23822, (National Aeronautics and Space Administration, Johnson Space Center)

[4] *Acoustic Noise Control Plan for ISS payloads,* NASA SSP 57010B, Appendix D, (National Aeronautics and Space Administration)

[5] *Noise Measurement Procedures,* JSC 23822, Appendix A, (National Aeronautics and Space Administration, Johnson Space Center)

[6] *Acoustics – Determination of sound power levels of noise sources using sound pressure – Engineering method in an essentially free field over a reflecting plane*, International Standard ISO 3744, (International Organization for Standardization, Geneva, Switzerland).

[7] *Acoustics – Determination of sound power levels of noise sources – Survey method,* International Standard ISO 3746, (International Organization for Standardization, Geneva, Switzerland).

[8] Ron Moulder, "Sound-Absorptive Materials", Chap. 3 in Noise control in buildings, edited by Cyril M. Harris, (McGraw Hill, New York, 1994)

[9] Beth A. Cooper, personal communication

Table 1: Octave-band Limit Values for Continuous Noise, dB (NC-40)

Octave Band Center Frequency [Hz]	Integrated Rack Sound Pressure Level [dB]
63	64
125	56
250	50
500	45
1000	41
2000	39
4000	38
8000	37

Table 2: A-weighted Limit Values for Intermittent Noise, dBA

Maximum Rack Noise Duration [hh:mm]	Integrated Rack Sound Pressure Level [dB]
8:00	49
7:00	50
6:00	51
5:00	52
4:00	54
3:00	57
2:00	60
1:00	65
0:30	69
0:15	72
0:05	76
0:02	78
0:01	79
Not Allowed	80

Table 3: Small Conference Room Example (4.3m x 5.2m x 2.4m high)

	Area	63	125	250	500	1000	2000	4000	8000
Curtains over wall	6.3	*0.18*	0.35	0.25	0.18	0.27	0.37	0.42	*0.42*
Gypsum board wall	26.0	*0.15*	0.29	0.10	0.05	0.04	0.07	0.09	*0.10*
Plaster wall	10.8	*0.07*	0.14	0.10	0.06	0.04	0.04	0.03	*0.03*
Sound absorbing foam	17.1	*0.40*	*0.80*	1.00	1.19	1.21	1.18	1.13	*1.13*
Carpeted floor	20.3	*0.05*	0.10	0.16	0.11	0.30	0.50	0.47	*0.47*
Acoustic tile ceiling	22.1	*0.15*	0.31	0.34	0.49	0.74	0.75	0.64	*0.50*
Acoustic wedges	11.9	*0.85*	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Plywood	1.9	*0.28*	0.28	0.22	0.17	0.09	0.10	0.11	*0.11*
Surface Area	116.4								
Measurement Surface Area	19.0								
Absorption ($\Sigma S_i \alpha_i$)		28	46	45	49	58	63	60	57
$\Sigma S_i \alpha_{ii} / S_m$		1.5	2.4	2.4	2.6	3.1	3.3	3.2	3.0
K_2 [dB]		**6**	**4**	**4**	**4**	**4**	**3**	**4**	**4**

Table 4: Warehouse Example (20m x 20m x 10m high)

	Area	63	125	250	500	1000	2000	4000	8000
Concrete Floor	400	*0.01*	0.01	0.01	0.02	0.02	0.02	0.02	0.02
Gypsum board wall/ceiling	1200	*0.15*	.029	0.10	0.05	0.04	0.07	0.09	*0.10*
Surface Area	1600								
Measurement Surface Area	19.0								
Absorption ($\Sigma S_i \alpha_i$)		184	352	124	66	56	92	116	128
$\Sigma S_i \alpha_{ii} / S_m$		9.7	18.6	6.5	3.5	3.0	4.9	6.1	6.8
K_2 [dB]		**1**	**1**	**2**	**3**	**4**	**3**	**2**	**2**

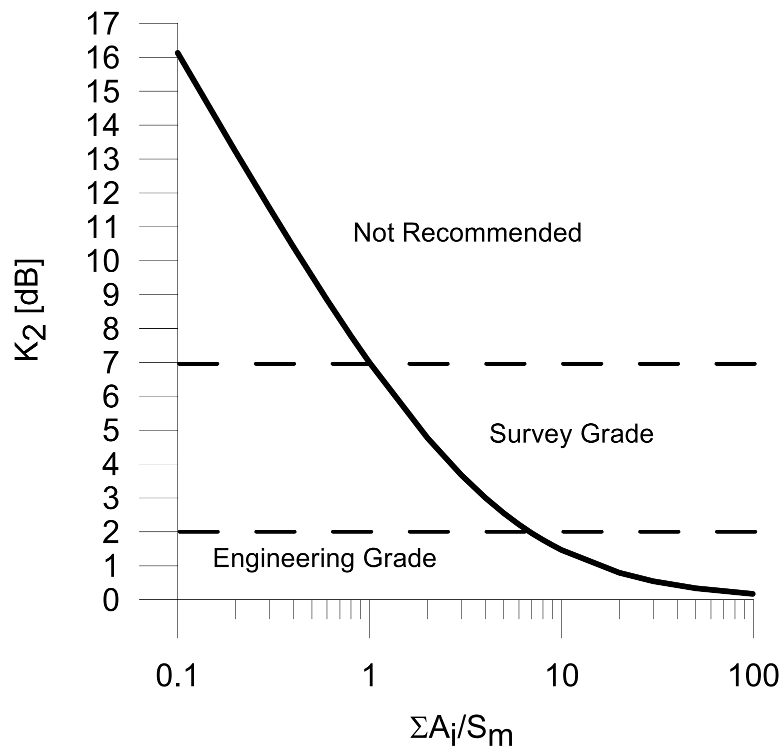

Figure 1: Environmental Correction Factor

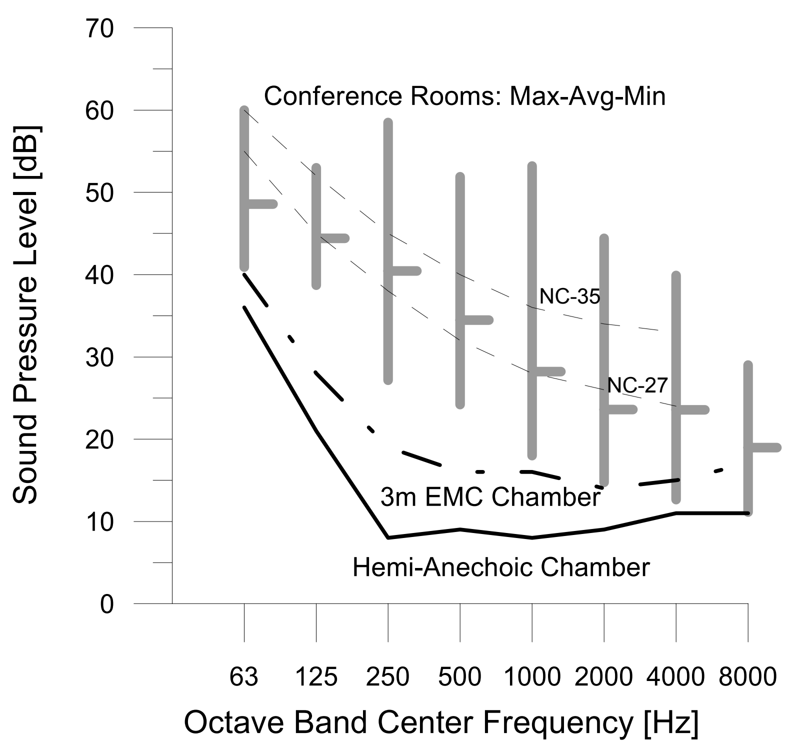

Figure 2: Range of Ambient Noise