NASA Glenn Research Center
Acoustical Testing Laboratory

Field Test Procedure –

Measurement of noise emitted by spaceflight hardware for assessing compliance with NASA SSP 57000G

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1 Scope

1.1 General

This field test formalizes a method for measuring the emission sound pressure levels of payloads and racks intended to reside on the International Space Station (ISS). It is intended to provide guidance for the Acoustical Testing Laboratory staff in cases where noise emission measurements must be made in situ, (e.g., when a test article may not be transported to the ATL). This document may be a helpful reference for payload developers who do not have access to an acoustical laboratory and are considering the merits of candidate environments for acquiring acoustical measurements.

Compliance criteria are called out in NASA SSP 57000, Revision G " *Pressurized Payload Interface Requirements Document"*. Testing requirements are described in SSP 57010B, Appendix D " *Acoustic Noise Control Plan for ISS payloads"* and JSC 23822 "*ISS Acoustic requirements and testing document for ISS non-integrated equipment*".

Nothing in this document is intended to alter, contradict, or supersede criteria contained in the aforesaid documents. Its purpose is to consolidate and clarify testing requirements for ISS payloads. Furthermore it is hoped that this document will assist others in the aerospace community in their efforts to make reliable measurements of noise emission.

1.2 Types of noise and noise sources

The methods specified in this standard apply specifically to racks and payloads which are significant noise sources operating both continuously and intermittently.

Some payloads do not form an integrated or well-defined rectangular package at the time of test. The definition of measurement surface used in this procedure accommodates these as well.

Testing methods for individual components are not covered by this procedure. The NASA Interface Requirements documents do not specify tests for individual components or subassemblies. It is the opinion of the ATL that these are best evaluated using sound power measurement standards.

1.3 Testing environment

The test environment influences the accuracy of the determination of emission sound pressure levels. An “essentially free field” over a reflecting plane is desired, which means that sound reflecting surfaces are kept to a minimum. A hemi-anechoic chamber (sound-absorbing wedges on walls and ceiling, reflective floor) provides an optimal environment. If one is not available, a dedicated acoustic test room with sound absorbing walls is likely to be adequate. Other informal spaces such as EMI chambers, conference rooms, auditoria, and warehouses, must be considered on the basis of their size, surface treatments, and ambient noise levels. In general, acoustic reflections and ambient noise tend to bias measurement results upward.

Outdoor sites are often used to provide an excellent approximation of a free field. In practice, however, environmental noise factors make it all but impossible to achieve NASA's criterion levels at most outdoor sites. Thus outdoor sites are not covered by this test procedure.

Methods for estimating the impact of acoustic reflections in the test environment are given in Annex A. Criteria for assessing acceptability thereof are given in 4.3.3.

It is not possible to estimate ambient noise levels in a given space. It can only be measured directly. Results of a survey of informal spaces are presented in Annex B. Criteria for assessing acceptability are given in 4.3.4.

1.4 Measurement Uncertainty

No acoustical measurement is absolutely accurate. Factors such as test environment, ambient noise, location of microphones, duration of measurement, variability of the noise source, presence of support equipment or an operator in the test room, and quality of sensors and measurement equipment all provide some degree of measurement uncertainty.

The uncertainty of measurements performed according to this procedure cannot be determined precisely in advance because of the potentially unlimited range of test environments. The uncertainty estimates below have been derived from the stated uncertainties of several acoustical test standards as well as uncertainty estimates from testing at ATL.

The quality of the acoustic environment within which the tests are performed has a direct influence on the accuracy of the measurements. Desirable properties of a test environment include the damping of sound reflections and adequate isolation from background noise. The presence of reflective surfaces and/or background noise generally increases measured values.

The uncertainty varies with the environmental indicator K_2 and the presence of prominent discrete tones, and corresponds to the standard deviation of reproducibility (lab-to-lab variation). Smaller K_2 values indicate a closer approximation to the ideal free field environment. Evaluation or estimation of K_2 is described in Annex A.

	Broadband			**With Prominent Discrete Tones**		
Band	$K_2 = 2$	$K_2 = 5$	$K_2 = 7$	$K_2 = 2$	$K_2 = 5$	$K_2 = 7$
Standard Deviation of Reproducibility	2.5	5.0	6.5	3.5	6.5	8.0

1.5 Use of “shall” and “should”

The word “shall” is used to describe an absolute requirement for this test procedure; the measurement is only valid if the requirement is met. The word “should” is used to describe a condition that is strongly encouraged to be achieved where practicable.

Test conditions that do not conform to the “shall” and “should” requirements of this document shall be noted in the test report.

2 References

ISO 11201:1995(E) - Acoustics-Noise emitted by machinery and equipment-Measurement of the emission sound pressure levels at work station and other specified positions-Engineering method in an essentially free field over a reflecting plane.

ANSI S1.4-1983	American National Standard specification for sound level meters
ANSI S1.4A-1985	Amendment to S1.4-1983
ANSI S1.11-1986	American National Standard specification for octave-band and fractional-octave-band analog and digital filters
ANSI S1.40-1984	American National Standard specification for acoustical calibrators
ANSI S12.5-1990	American National Standard requirements for the performance and calibration of reference sound sources
ANSI S12.54-1999	Determination of sound power level of noise sources using sound pressure – Engineering Method in an essentially free field over a reflecting plane
ANSI S12.56-1999	Determination of sound power level of noise sources using sound pressure – Survey Method using an enveloping measurement surface over a reflecting plane
IEC 651:1979	Sound level meters
IEC 804:1985	Integrating-averaging sound level meters
IEC 942:1988	Sound calibrators
IEC 1260	Electroacoustics – Octave-band and fractional-octave-band filters
ISO 3744:1994	Acoustics - determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane.
ISO 3745:1977	Acoustics - determination of sound power levels of noise sources - precision methods for anechoic and Hemi-Anechoic rooms
ISO 3746:1995	Acoustics-determination of sound power levels of noise sources using sound pressure - survey method using an envelop in measurement surface over a reflecting plane
ISO 11201	Acoustics - Noise emitted by machinery and equipment - guidelines for the use of basic standards for the determination of emission sound pressure levels and workstation and other specified positions.

3 Definitions

For the purpose of this standard the following definitions apply. More detailed definitions may be found in formal standards and acoustical texts.

3.1 Acoustical quantities

emission: Airborne sound radiated by a well-defined noise source (e.g. the device under test).

emission sound pressure, p**:** The sound pressure, at a specified position near a noise source, when the source is in operation under specified operating conditions over a reflecting plane surface, excluding the effects of background noise as well as the effects of reflections other than those from the plane or planes permitted for the purpose of the test. It is expressed in pascals.

emission sound pressure level, L_P: 10 times the logarithm to the base 10 of the ratio of the square of the emission sound pressure, $p^2(t)$, to the square of the reference sound pressure, p_0^2, measured with a particular time weighting and a particular frequency weighting. It is expressed in decibels. The reference sound pressure is 20 micropascals.

impulsive sound level, $L_{PA,I}$: 10 times the logarithm to the base 10 of the ratio of the square of the emission sound pressure, $p^2(t)$, to the square of the reference sound pressure, p_0^2, measured with an impulse time weighting and A-weighted filtering. It is expressed in decibels. The reference sound pressure is 20 micropascals.

maximum octave band sound pressure level, L_{PmaxS}: for the purposes of this test procedure, the highest emission sound pressure level attained in a given octave band during the measurement period using the Slow (s) time constant.

maximum sound level, $L_{PA,maxS}$: for the purposes of this test procedure, the highest A-weighted emission sound pressure level attained during the measurement period using the Slow (S) time constant.

time-averaged sound level, $L_{PA,eq}$, the sound pressure level of a continuous, A-weighted steady sound ($p_A(t)$)that, within a measurement time interval T, has the same mean-square sound pressure as a sound under consideration that varies with time.

It is expressed in decibels and is given by the following equation:

$$L_{PA,eq} = 10\log_{10}\frac{1}{T}\int_0^T \frac{p_A{}^2(t)}{p_0{}^2} \quad dB$$

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It is expressed in decibels and is given by the following equation:

$$L_{P,eq} = 10\log_{10}\frac{1}{T}\int_0^T \frac{p^2(t)}{p_0{}^2} \quad dB$$

3.2 Test environments and related quantities

background noise: the noise from all sources other than the machine under test. Also referred to as ambient noise.

background noise level: The sound pressure level measured when the machine under test is not operating. It is expressed in decibels.

background noise correction, K_1: a term that quantifies the influence of background noise on the emission sound pressure level at the specified positions of the machine under test. K_1 is frequency dependent and is expressed in decibels. Correction in the case of A-weighting, K_{1A}, is to be determined from A-weighted measured values.

$$K_1 = -10\log_{10}\left(1 - 10^{-0.1\Delta L}\right)$$

where ΔL is the difference between the sound pressure levels measured, at a specified position, with the machine under test in operation and turned off, respectively.

environmental indicator, K_2: a term that quantifies the potential increase of the measurement surface sound pressure level due to reflected or absorbed sound. K_2 depends on the measurement surface or point selected, is frequency dependent and is expressed in decibels. In the case of A-weighting, it is denoted K_{2A}. Methods for estimating or determining K_2 are provided in Annex A.

found space: an enclosed space used for acoustical testing on the basis of expediency. Conference rooms, workshops, warehouse spaces, auditoria, etc. are all used from time to time for acoustical testing. The acoustical properties of such spaces usually depart significantly from ideal performance; the environmental correction factor K_2 can be large. Experience has shown that room dimensions should be greater than 4 m by 6 m. Judicious sound absorptive treatment of a found space can improve acoustical performance.

free-field chamber: an acoustical test chamber consisting of a sound-isolating exterior shell, a sound-reflective floor ($\alpha < 0.10$), and an interior lining of sound absorbing material on walls and ceiling. In such spaces the environmental correction factor K_2 is generally less than 2 dB for octave bands with center frequencies of 250 Hz and above, and is appropriate for "engineering grade" tests.

free-field over a reflecting plane: sound field in a homogeneous, isotropic medium and half-space above an infinite, rigid plane surface on which the machine under test is located. The sound field is assumed to be substantially free of significant reflections caused by surfaces associated with the test environment.

hemi-anechoic chamber: an acoustical test chamber consisting of a sound-isolating exterior shell, a vibration-isolated sound-reflective floor ($\alpha < 0.10$), and an interior lining of sound absorbing wedges on walls and ceiling ($\alpha > 0.99$). In such spaces the environmental indicator K_2 is considered to be negligible.

3.3 Compliance-related concepts

compliance verification point: the point on the measurement surface at which the highest maximum emission sound level is measured.

continuous noise source: any individual item of equipment, or group of equipment items, that constitutes a significant noise source for a cumulative total of eight hours or more in any 24-hour period.

DUT: device under test, i.e., a rack or payload.

impulsive noise: a noise whose spectral amplitudes fluctuate significantly with time. See "stationary noise". A vehicle backup alarm is an example of a non-stationary noise. For the purposes of this procedure, an impulsive noise source is defined as one for which the impulsive sound level ($L_{PA,I}$) and the time-averaged sound level ($L_{PA,eq}$) differ by more than 3 dB.

intermittent noise source: any individual item of equipment, or group of equipment items, that constitutes a noise source greater than NC 40 for a cumulative total of less than eight hours in any 24-hour period.

measurement surface: a hypothetical surface parallel to an exterior surface of the device under test and located at a distance of 600 mm. Each surface extends to the lines of intersection with other measurement surfaces and, for non-horizontal surfaces on floor-mounted equipment, to the reflecting plane. For a disjoint package (consisting of several elements) the elements should be arranged as they would be in an actual payload or rack, and the measurement surface is located at a distance of 600 mm from the rectangular parallelepiped just enclosing all the elements.

operational cycle: a specific sequence of operational periods occurring while the machine under test performs a complete work cycle. Each operational period is associated with a specific process that may occur only once, or may be repeated, during the operational cycle (e.g. for a dishwasher the sequence washing, rinsing, drying might constitute an operational cycle).

operational period: interval of time during which a specified process is accomplished by the machine under test (e.g. for a dishwasher, washing, rinsing, and drying each constitute operational periods).

significant noise source: any individual item of equipment, or group of equipment items, which collectively function as an operating system, that generates a maximum sound level equal to or greater than 37 dBA at any point on a measurement surface at any time during an operational period.

stationary noise: a noise whose spectral amplitudes do not fluctuate with time. See "impulsive noise". A blower is an example of a stationary noise. For the purposes of this procedure, an impulsive noise source is defined as one for which the impulsive sound level ($L_{PA,I}$) and the time-averaged sound level ($L_{PA,eq}$) differ by 3 dB or less.

4 Preliminary Activities

4.1 Preliminary Documentation

4.1.1 Test Request/Specimen Documentation Forms

Test Requests are initiated by completing a Test Request Form on the NASA GRC website. Upon completion, the Test Request forms are transmitted electronically to the Laboratory Technical Manager. The Test Request is reviewed by the Laboratory Technical Manager to determine if the laboratory can provide the requested services. If the laboratory can provide the requested services, the Laboratory Technical Manager will schedule the test. The Laboratory Technical Manager will notify the Laboratory Engineer that the test will be scheduled and the Laboratory Engineer will assign a test number and schedule a test planning meeting.

Notes from any additional telephone conversations and meetings regarding the test request shall be included with the Test Request Forms.

4.1.2 Assign Test Number

A test number is assigned to a scheduled test in accordance with the numbering procedure outlined in the laboratory Document Control Program.

4.1.3 Assign Test Date(s)

Test dates are assigned based on the customer's requested schedule and laboratory availability.

4.1.4 Test File

Create the test file, which must incorporate documentation of the test specimen, the test environment and the test results. Identify and create placeholders for all data required in Section 8.

4.2 Select Instrumentation

Instrumentation must be selected with a view to the ultimate criterion to be satisfied, as well as the potential need to provide diagnostic information for noise control efforts.

4.2.1.1 Precision

The instrumentation system, including the microphone in cable, should meet the requirements of Class 1 instruments specified in IEC 651, IEC 804 and IEC 1260, or ANSI S1.4, ANSI S1.4a and ANSI S1.11.

> *Note - This corresponds to the requirements of test standards of precision and engineering grade. NASA SSP 57000G does not mention a required precision for sound measurement equipment. JSC 28322 requires a Type 1 Meter (strictly speaking, JSC 28322 applies only to non-integrated equipment).*

4.2.1.2 Filtering Capability

If measurements are to be performed on continuous noise sources (operating more than 8 hours per day) the acoustic analyzer shall have A-weighted and octave band filters. These analyses should preferably be performed simultaneously. The A-weighted sound pressure level shall be directly measured rather than computed from band levels after the fact.

If measurements are to be performed on intermittent sources only, the acoustic analyzer need only have an A-weighted filter.

> *Note: Diagnostic tests are part of good engineering practice and are necessary for effective noise control efforts in the event that the hardware does not conform to the criterion. Effective diagnostic measurements must have narrower bandwidth than the criterion that is to be satisfied. For instance, in order to provide data useful for improving an A-weighted result, octave band measurements would be required at minimum. In order to provide data useful for improving an octave band result, one-third octave band measurements would be required. In either case, narrowband (FFT) analysis is extremely useful for source identification and root cause analysis.*

4.2.1.3 Time Averaging

NASA SSP 57000G does not mention time averaging parameters for sound level measurement. The only NASA document that mentions time averaging (JSC 28322) requires that the reported sound level be the highest reading using a SLOW time constant (Max Slow) during operation.

ATL laboratory practice is to use the equivalent sound pressure levels (L_{EQ}) unless the impulsive sound level ($L_{PA,Ii}$) is 3 dB or more greater than the time-averaged sound level ($L_{PA,eq}$). If the sound is impulsive, the sound pressure levels reported shall be the highest reading using the SLOW time constant.

4.2.1.4 Measurement Duration

For stationary noise, the measurement duration shall be no less than 15 seconds for A-weighted measurements and for octave band measurements at or above a center frequency of 250 Hz. For octave band measurements below 250 Hz, the measurement duration shall be no less than 30 seconds.

For impulsive noise, the measurement duration shall be equal to an integer number of operational periods.

4.2.1.5 Spatial Resolution

NASA SSP 57000G requires that the reported sound level be measured 0.6 meters from the noisiest part of the rack. JSC 28322 mentions a “roving sweep in the A-weighted mode”, which permits the identification of the “noisiest” point on the measurement surface. This is practical only for noises that are stationary and continuous in character.

ATL laboratory practice is to provide a dense grid of fixed microphones and sample them simultaneously in order to locate the noisiest point on the measurement surface, which is superior for intermittent and/or non-continuous noise. If a multi-channel system is not available, microphones shall be placed sequentially at the compliance verification point for each face of the measurement surface. The compliance verification point is in turn determined based on a survey of gridded points at 150 mm spacing on each face, or a continuous hand sweep.

4.2.1.6 Quality Assurance

The compliance of the calibrator with the requirements of IEC 942 or ANSI S1.40 shall be verified once a year or as determined under a Laboratory Quality system conforming to ISO Guide 17025. The date of the last verification of the compliance with relevant IEC or ANSI standards shall be recorded.

The compliance of the instrumentation system with its requirements shall be verified at least every two years or as determined under a Laboratory Quality system conforming to ISO Guide 25 and/or ANSI Z540. The date of the last verification of the compliance with relevant IEC or ANSI standards shall be recorded.

4.3 Select the Test Space

The test space should be selected based on its size, interior surface treatments, and ambient noise environment. A large room with sound absorbing surfaces and low ambient noise levels is desired.

4.3.1 Size

The selected test space should be as large as possible. It should have a minimum width of 6 meters, and shall have a minimum width of 4 meters. Sound reflective surfaces or objects such as bookcases, etc., shall be removed from the test space altogether or placed at least 3 m from the test article.

4.3.2 Surface Treatments

In general, larger rooms with greater coverage of sound absorbing material perform better. Thicker sound absorbers absorb more low-frequency energy. K_2 may be assumed to be negligible for indoor environments which are laboratory hemi-anechoic rooms and meet the requirements of Section 9 of ANSI S12.35-1990.

The acoustic absorption coefficient of the reflecting plane should be less than 0.10 over the frequency range of interest. Wooden, steel, concrete, and tile floors are typical.

The acoustic absorption coefficient of wall and ceiling surfaces should be high enough to achieve the K_2 requirements of 4.3.3 below.

4.3.3 Criteria for Acoustic Reflections

Annex A describes a procedure for determining or estimating the environmental indicator K_2 based on the geometry and surface treatments of the proposed test room.

The environmental indicator K_2 should be less than 2 dB in all octave bands of interest and A-weighted. This corresponds to the requirements of sound power test standards with engineering grade precision.

The environmental indicator K_2 shall be less than 5 dB in all octave bands of interest and A-weighted. This corresponds to the requirements of sound power test standards with survey grade precision.

If an environmental indicator K_2 of greater than 7 dB is present in any octave band of interest, the space is considered unsuitable for acoustic testing.

If an environmental indicator K_2 of greater than 2 dB is present in any octave band of interest, efforts should be made to improve the acoustical environment by removing reflecting objects and adding sound absorbing materials.

4.3.4 Criterion for Ambient Sound Pressure Levels

Ambient sound pressure levels shall be measured near the center of the proposed test space. The ambient sound pressure levels shall be no greater than the criterion value minus 3 dB in each band of interest. The ambient sound pressure levels should be no greater than the criterion value minus 10 dB in each band of interest.

If a differential of 10 dB or greater is not achieved, efforts should be made to improve the acoustical environment by eliminating sources of noise (e.g., turning of HVAC systems).

5 On-Site Activities

5.1 Test Space Setup

5.1.1 Room Setup

Remove any test space contents that could reflect sound and/or reduce the working volume. If they cannot be removed, move them to locations at least 3m away from the test article.

Minimize sources of continuous ambient noise by turning down or off HVAC systems and other building services, sealing penetrations to adjacent spaces, and if necessary waiting for environmental noises (due to traffic, wind, etc.) to abate.

Remove or disable sources of intermittent ambient noise such as telephones, intercoms, paging systems, door buzzers, etc. The space should be protected from surprise visitors and curious onlookers by appropriate “test in progress” signage.

Sound analysis equipment, such as spectral analyzers, should be located outside of the test chamber and connected to microphones by cables passed through sealed ports. This is especially true for fan-cooled analysis equipment.

In the event that the sound analysis equipment and/or its operator must be located inside the test chamber, any operational noise that it/they make(s) shall be included in measurements of the chamber’s background noise.

5.1.2 Test Article Setup

In the case of a flight rack, the rack and its rack-handling adapter should be placed on the floor near but not at the center of the chamber and oriented so as to not be parallel with the walls. If the environmental indicator K_2 is greater than 2.0 dB in any band of interest, the device under test shall be oriented so that its principal axes diverge from the principal axes of the chamber by at least 15 degrees. The geometric center of the device under test shall also be no closer than 350 mm in plan to the plan center of the test chamber. The dimensions of the test chamber shall be sufficient that a distance of 1.3 meters or more remains between the device under test and the test chamber wall surfaces or other reflecting surfaces, although a distance of 2.0 meters is preferred and should be observed where practicable.

In the case of a payload, it may be placed on a small table or stand 1.0 m high, and located in accordance with the foregoing paragraph. The table should not extend past the envelope of the payload in order to minimize the effect of reflections from the table.

5.1.3 Mounting of Source

The manner in which the machine under test is installed and operated may have a significant influence on the emission sound pressure levels.

The noise emission of the device under test may depend upon support and mounting conditions. It is customary that whenever a typical mounting condition exists for a device, that condition shall be used or simulated if practicable.

When a table is used, it shall be massive and well-damped (e.g., "butcher block" table). The payload shall be supported so as to eliminate rattling. The mounting of the source shall be fully described in the test report.

Where a measurement of noise emission from the bottom of a payload is required, it is common to invert the payload and measure above it. When it is impractical to invert the payload, it may be laid on its side.

If sound power level tests are planned, the same installation, mounting and operating conditions shall be used for both tests.

5.1.4 Auxiliary Equipment

Care shall be taken to ensure that any auxiliary equipment or service connections do not radiate significant amounts of sound energy into the test environment.

If practicable, all auxiliary equipment (not a part of the flight rack or payload) should be located outside the test environment. This test procedure requires that noise emitted by the auxiliary equipment be measured along with the ambient so that it can be corrected out. (Note: the ISS interface guidelines do not explicitly permit ambient noise corrections to be used to demonstrate compliance.)

5.2 Instrumentation Setup and Operation

5.2.1.1 Warmup

Place the microphone on its preamplifier and complete all connections to the sound level meter. Turn the meter on, along with any other outboard equipment used to power the microphone, and observe the manufacturers' recommended warmup time. If the warmup time is unknown, wait 10 minutes.

5.2.1.2 Microphone Stand

The microphone stand shall be of sufficient height to reach the top of the payload or flight rack and allow the microphone to be properly oriented. For free-field microphones, this means that the axis of the microphone cartridge can be oriented perpendicular to the measurement surface. A boomstand may be required for measurements above the DUT.

Other ambient conditions may have an adverse effect on the microphone used for the measurements. Such conditions (strong electromagnetic fields, wind, high or low temperatures, precipitation, or impingement of air discharge from the device under test) shall be avoided by proper selection and positioning of the microphone.

5.2.1.3 Configure Analyzer

Steps for configuring the acoustic analyzer or meter vary between models. The operator should be well familiar with equipment operation.

5.2.2 Calibrate Microphone

Before (and after) a series of measurements, a sound calibrator with an accuracy of ± 0.3 dB (Class 1 as specified in IEC 942 or ANSI S1.40) shall be applied to the microphone to verify the calibration of the entire measuring system at one or more frequencies over the frequency range of interest.

Before making measurements subsequent to calibration, affix a windscreen to the microphone.

5.2.3 Orientation of microphones

The microphone(s) shall be oriented in such a way that the angle of incidence of the sound coincides with the reference direction of the microphone as specified by the manufacturer to meet the requirements of by IEC 651/804 or ANSI S1.4/S1.4a.

The majority of microphones are "free field" type, which means that the axis of the microphone points directly at the sound source.

5.2.4 Location of Operator

In the event that the operator or an observer must be inside the test space during the test, they should be located as far away from the device under test and microphones as practicable. Under no circumstances shall they pass between microphones and the device under test.

The operator or observer, if present, should not wear clothing with abnormal sound-reflective properties other than protective equipment required for safety reasons and should avoid carrying sound-reflective items into the test space (e.g., clipboard). In such a case the operator or observer should also be present in the test space during background noise level measurements.

5.2.5 Compliance Verification Points

On each face of the measurement surface, define a grid of test points at 150 mm intervals (horizontally and vertically). Add additional test points directly opposite any audible noise source.

Measure the maximum emission sound level ($L_{P,maxS}$) at each test point on the measurement surface.   The test point having the highest maximum emission sound level is designated as the compliance verification point.

Alternatively, a slow continuous hand sweep may be performed. The total duration of the sweep should not be less than the number of gridded test points on that face of the measurement surface times 15 seconds.

Note that this point may differ between operations and should be assessed separately for each operational period.

5.2.6 Configure Test Space

Configure the test space in preparation for data acquisition. The following actions should be performed, as applicable to the test space, each time a person has entered the test space immediately prior to a test:

- Seal utility penetrations
- Examine interior of test space for changes
- Turn off intercom
- Configure HVAC
- Record Environmental Conditions
- Close doors and verify seals
- Examine test room exterior for changes
- Activate “Test in Progress” light or place signs

6 Measurements

The following measurements are to be performed at each compliance verification point.

6.1 Ambient Measurement

Measure the time-averaged sound level and time-averaged octave band sound pressure levels at the compliance verification point with the DUT turned off. Auxiliary equipment supporting the device under test should be operated if practicable.

6.2 DUT Measurement

Measure the time-averaged sound level and time-averaged octave band sound pressure levels at the compliance verification point with the DUT operating.

Determine whether the noise is impulsive by comparing the impulsive sound level ($L_{PA,I}$) and the time-averaged sound level ($L_{PA,eq}$). If they differ more than 3 dB, measure the maximum emission sound level ($L_{PA,maxS}$) and maximum emission sound pressure levels ($L_{P,maxS}$).

6.2.1 Repeating measurements

If variations in noise emission are noticeable between successive operational periods or cycles, it may be desirable to average the results of several measurements. If so, the test should be performed three or more times. Average values shall be calculated as

$$L_{avg} = 10\log_{10}\frac{\sum_i 10^{0.1L}}{N}$$

where

L is any sound level or sound pressure level measured in accordance with this standard.

6.2.2 Check signal-to-noise ratio

At each compliance verification position, the measured sound pressure level in each octave band and A-weighted due to the background noise shall be at least 3 dB below the emission sound pressure level in that band with the source operating ($K_1 \le 3.0$ dB). This corresponds to the requirements of survey grade sound power test standards.

At each microphone position, the measured sound pressure level in each octave band and A-weighted due to the background noise should be at least 10 dB below the emission sound pressure level in that band with the source operating ($K_1 \leq 0.5$ dB). This corresponds to the requirements of engineering grade sound power test standards.

> *Note: this check is necessitated because of the potential influence of auxiliary equipment not present during preliminary checks (4.3.4) or of changes in test space ambient noise levels due to changes in support equipment operation or other environmental noise factors.*

6.2.3 Optional measurements

Other quantities, such as one-third octave band spectra, narrowband spectra, impulsiveness, audio files, etc. may also be measured or recorded to support the design of low-noise equipment. These measurements are not covered by this standard.

7 Quantities to be determined

7.1 Background-corrected sound pressure levels for intermittent noise sources

Background noise corrections K_1 may be applied to measured sound pressure levels. Although common practice within the acoustical measurement community, these corrections are for information only because the interface guidelines do not explicitly permit ambient-corrected levels to be used to demonstrate compliance.

Corrections K_1 are those relevant to the frequency weighting or frequency bands for which sound pressure levels have been measured. For frequency bands and A-weighting, respectively:

$$L_p = L'_p - K_1$$
$$L_{pA} = L'_{pA} - K_{1A}$$

where prime denotes measured values and no prime indicates emission values.

7.2 NC-rating for continuous noise sources

For a continuous noise source, determine the NC rating of the maximum octave band sound pressure levels measured at the compliance verification point. Optionally, an NC-rating may be computed for the maximum emission octave band sound pressure levels.

7.2.1 Determination of NC rating

Octave band sound pressure levels corresponding to each NC curve are given below in Table 2. Each NC curve carries a numerical descriptor (e.g., for NC 30 the numerical descriptor is 30). Integer-valued NC curves are commonly interpolated between the tabulated curves.

For each octave band, find the numerical descriptor of the NC curve whose value equals the sound pressure level. If the data lies between two curves, the numerical designator of the next-highest curve is used. The highest numerical descriptor amongst the octaves is the NC rating of the sound.

Table 2: NC Curves as Sound Pressure Levels vs. Octave Band

NC Rating	63	125	250	500	1000	2000	4000	8000
	Octave Band Center Frequency [Hz]							
NC 20	51	40	33	26	22	19	17	16
NC 25	54	44	37	31	27	24	22	21
NC 30	57	48	41	35	31	29	28	27
NC 35	60	52	45	40	36	34	33	32
NC 40	64	56	50	45	41	39	38	37
NC 45	67	60	54	49	46	44	43	42
NC 50	71	64	58	54	51	49	48	47
NC 55	74	67	62	58	56	54	53	52
NC 60	77	71	67	63	61	59	58	57

Source: ASHRAE

7.2.1.1 *Example*

An octave band spectrum is tabulated below along with the corresponding NC classification for each octave and the overall rating. Most of the values fall directly on NC curves and adopt that number, but the spectrum at 1000 and 4000 Hz has been linearly interpolated. The overall NC-rating of the measured sound is NC-38 which is controlled by the result at 4 kHz.

	63	125	250	500	1000	2000	4000	8000
Spectrum	**51**	**44**	**41**	**40**	**38**	**34**	**36**	**27**
NC 20	51	40	33	26	22	19	17	16
NC 25	54	44	37	31	27	24	22	21
NC 30	57	48	41	35	31	29	28	27
NC 35	60	52	45	40	36	34	33	32
NC 40	64	56	50	45	41	39	38	37
NC Classification	20	25	30	35	37	35	38	30
NC Rating	**38**							

8 Information to be recorded

The information below shall be recorded, catalogued, and placed in the test file.

8.1 General

General information regarding test, including

- Test designation
- Name of testing entity
- Name of test engineer and technician(s)
- Date
- Time
- Atmosphere conditions: temperature, relative humidity, barometric pressure

8.2 Device under test

Description of the device, including its

- Designation
- Technical data
- Dimensions
- Manufacturer
- Serial number
- Installed components
- Components missing or not yet installed
- Revision Stage or other identifying information to permit determination after the fact which sound sources were present and operating during test

8.3 Test conditions

- Precise quantitative description of operating conditions and, if relevant, operational periods and cycle
- Mounting conditions
- Location of the device in the test environment
- If the device under test has multiple noise sources, description of the sources in operation during the measurements
- Description and location of auxiliary equipment
- Description of noise sources included in background noise level measurements

8.4 Acoustic environment

Description of the test environment:

- If indoors, description of physical treatment of walls, ceiling and floor; sketch showing the location of the device under test and room contents; acoustical qualification of room in accordance with 4.1.
- If outdoors, sketch showing the location of the device under test with respect to surrounding buildings and terrain including physical description of test environment and wind speed in meters per second.

8.5 Instrumentation

- Equipment used for measurements, including name, type, serial number and manufacturer
- Method used for verifying the calibration of the measuring system
- Date, place and results of most recent system calibration
- Characteristics of windscreen (if any)

8.6 Measurement locations

A precise quantitative description shall be recorded of all measurement points, including

- gridded points on measurement surfaces
- added points on measurement surfaces, and
- conformance verification points.

8.7 Noise data

- Maximum emission sound levels at gridded points and added points on measurement surfaces,
- Time-averaged sound level and sound pressure level at compliance verification points under ambient conditions,
- Time-averaged sound level and sound pressure level at compliance verification points under operating conditions,
- Difference between impulsive sound level and time-averaged sound level
- If impulsive, maximum sound emission levels at compliance verification points.
- Corrected sound pressure levels at conformance verification points.

9 Information to be reported

The report shall include all the data recorded per Section 8. For each individual test, the following information shall at minimum be reported and/or tabulated in a certificate report format.

9.1 General

General information regarding test, including

- Test designation
- Name of testing entity
- Name of test engineer and technician(s)
- Date
- Time
- Atmosphere conditions: temperature, relative humidity, barometric pressure

9.2 Device under test

Description of the device, including its

- Designation,
- Installed components,

9.3 Test conditions

- Description of the sources in operation during the measurements,

9.4 Measurement locations

- Description of compliance verification points.

9.5 Noise data

- Time-averaged sound level and sound pressure level at compliance verification points under operating conditions,
- Difference between impulsive sound level and time-averaged sound level
- If impulsive, maximum sound emission levels at compliance verification points.
- Corrected sound pressure levels at conformance verification points.

Annex A

A.1 Determination of the environmental indicator K_2

The environmental indicator K_2 accounts for the influence of undesired sound reflections from room boundaries and/or reflecting objects near the source under test. The magnitude of this environmental indicator depends principally on the ratio of the sound absorption area of the test room A to the aggregate area of the measurement surfaces S_M.

A.1.1 Estimate of the Sabine absorption

The average Sabine sound absorption A of the surfaces of the room in metric sabins, is estimated from:

$$A = \sum_i \alpha_i S_{R,i} = \langle \alpha \rangle S_R$$

where

$S_{R,i}$ = area of the i-th surface of the test room, in square meters,
S_R = total area of the surfaces of the test room, in square meters,
α_i = Sabine sound absorption coefficient of the i-th surface of the test room,
$<\alpha>$ = area-weighted average Sabine sound absorption coefficient of the test room surfaces.

Estimates of α_i are available in octave bands from numerous acoustical texts and from material manufacturers. Note that all surfaces (including the reflective floor included) must be accounted for in this computation.

Table 3 gives overall approximate values of the average Sabine sound absorption coefficient $<\alpha>$ for typical found spaces.

Table 3: Approximate values of the average Sabine absorption coefficient <α>

Average Sabine sound absorption coefficient <α>	Description of room
0.05	Nearly empty room with smooth hard walls made of concrete, brick, plaster, or tile
0.10	Partly empty room with smooth walls
0.15	Room with furniture, rectangular machinery room, rectangular industrial room
0.20	Irregularly shaped room with furniture, irregularly shaped machine room or industrial room
0.25	Room with upholstered furniture, machinery or industrial room with a small amount of acoustical material (for example, partially absorptive ceiling) or ceilings or walls

A.1.2 Estimate of the environmental indicator *K_2*

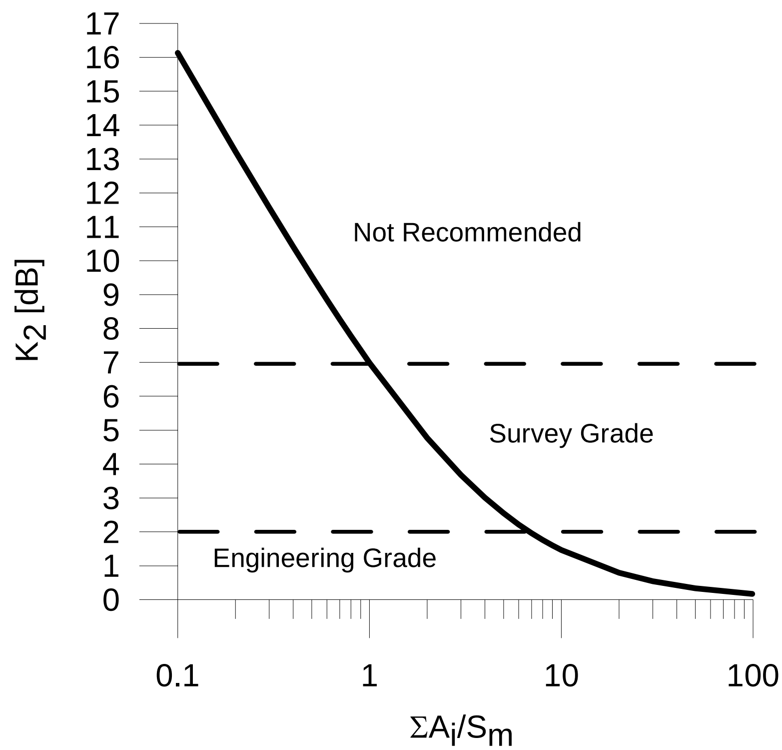
The environmental indicator K_2 may be estimated from the Sabine absorption of the test room A and the cumulative area of the measurement surfaces S_M as:

$$K_2 = 10\log_{10}\left[1 + 4\frac{\sum_i S_{M,i}}{\sum_i \alpha_i S_{R,i}}\right] = 10\log_{10}\left[1 + 4\frac{S_M}{A}\right]$$

where

$S_{M,i}$ = the area in square meters of the i-th measurement surface,
S_M = the cumulative area in square meters of all measurement surfaces.

In order for the value of K_2 to be less than 2 dB, the ratio A/S_M must be greater than 6.8.
In order for the value of K_2 to be less than 7 dB, the ratio A/S_M must be greater than 1.0.



A.1.2.1 Example: Small Conference Room (4.3m x 5.2m x 2.4m high)

The following example is worked out in octave bands using values derived from those available in acoustics texts. It shows that this small room meets the criterion of $K_2 < 5\ dB$ only with difficulty.

	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**

A.1.2.2 Example: Large Warehouse (20m x 20m x 10m high)

The following example is worked out in octave bands using values derived from those available in acoustics texts. It shows that this large room has a relatively easy time meeting the criterion $K_2 < 5\ dB$.

	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**

A.2 Measurement and Determination of the environmental indicator K_2

Alternatively, the environmental indicator K_2 may be determined by calculating the Sound Power Level of a reference sound source which has previously been calibrated in a free field over a reflecting plane per ANSI S12.5 or ISO 6926. In this case, K_2 is given by the expression

$$K_2 = L_W - L_{Wr}$$

where

L_W = the calculated sound power level, re 1 pW, in decibels, of the reference sound source as determined in the candidate test environment and using measurement positions located on the measurement surfaces described in this test standard,

L_{Wr} = the calibrated sound power level, re 1 pW, in decibels, of the reference sound source.

Annex B: Ambient Noise Survey of Informal Spaces

A study of ambient noise levels was conducted in several carefully screened candidate test spaces at NASA Glenn Research Center.

In order to test continuous rack noise sources, the maximum permissible ambient noise is approximately NC-37 (NC-40 criterion minus 3 dB.). The plotted NC-35 curve represents a slightly better signal-to-noise ratio ($K_1 \geq 1.7\ dB$ for NC-35 ambient and NC-40 measured result). Note that some of the candidate spaces were too noisy in one or more octave bands.

In order to test continuous payload noise sources, the requirements are stricter because criteria are typically on the order of NC-32. Thus the maximum permissible ambient noise would be approximately NC-29. The plotted NC-27 curve represents a slightly better signal-to-noise ratio ($K_1 \geq 1.7\ dB$ for NC-27 ambient and NC-32 measured result). Because the average results track near the NC-27 curve, it's likely that the majority of spaces surveyed would be too noisy in one or more octave bands.

Ambient sound pressure levels in ATL's Hemi-Anechoic Chamber and in a 3m EMC Chamber located in a quiet, dedicated building are displayed for comparison.