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Title: Environmental Performance and Durability Assessment of Condenser Microphones in Accordance with MIL-STD-810

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Abstract

This study evaluates the performance and environmental resilience of ¼”, condenser measurement microphones (IEC 61094) in battlefield applications, subjected to testing in accordance with MIL-STD-810, the military standard for environmental engineering and laboratory tests.

Condenser microphones with high dynamic range, and broad frequency range suited for high level impulsive measurements are essential in various military and industrial applications. They must be designed and manufactured to withstand harsh conditions without compromising the functionality. MIL-STD-810 provides a comprehensive suite of tests designed to replicate the environmental stresses that equipment might encounter in the field.

The investigation covers the evaluation of condenser microphones to a series of MIL-STD-810 test methods, including temperature extremes, humidity, vibration, mechanical shock, sand and dust exposure, and water immersion. These tests simulate rugged and varied environmental conditions very different from what measurement microphones normally face in laboratory conditions. Performance metrics such as frequency response, sensitivity, signal-to-noise ratio, and durability are rigorously measured before, during, and after exposure to these conditions.

The results of these tests offer a detailed understanding of the durability and operational limits of condenser microphones. Key findings indicate if the microphones meet or exceed military standards for environmental resilience, thereby ensuring reliability in critical applications. Additionally, the study has identified design improvements to enhance the robustness of these devices.

By adhering to MIL-STD-810 testing protocols, this research provides valuable insights into the environmental performance of condenser microphones, informing end-users about their suitability for deployment in extreme conditions. The study underscores the importance of rigorous environmental testing in the development and qualification of reliable acoustic sensor equipment for military and industrial use.

1. Introduction

Microphones were first used on the battlefield during World War I. The introduction of wireless communication systems, including radios, necessitated the use of microphones for transmitting voice communications. Today, microphones are used in multiple applications such as communication systems, hostile artillery location systems, sniper detection and location systems, and drone detection and tracking systems.

The acoustic environment on the battlefield is complex, with several sources of noise present:

- Combat Sounds: Impulsive noise sources from gunfire, explosions, and artillery. These can be very high in the near field and very low at longer distances.
- Mechanical Noise: Sounds from vehicles, helicopters, and drones contribute to the overall noise level.
- Environmental Sounds: Wind, rain, and other natural elements can add to the background noise.

At the same time the, noise is spread out over a large frequency range.

- Low-Frequency Noise: Explosions and heavy machinery generate low-frequency sounds that can travel long distances.
- High-Frequency Sounds: Gunshots, with both muzzle noise and bullet noise.

With this complex acoustic environment in mind, selection of microphones for battlefield applications is always a balance between price, performance and durability.

Less costly microphones are typically designed for consumer electronics and automotive applications where noise levels are usually not above 120dB and the background noise is somewhat limited. Exposing microphones designed for consumer electronics to noise levels of 150-160 dB will make the microphone inoperable, as it exceeds the microphones' Acoustic Overload Point, AOP.

The SPL of shockwave signals can reach levels as high as 160 dB, with a very short rise time. This often causes saturation and oscillations. Since meaningful signals can follow immediately after the shockwave, the microphone must have ultrashort recovery time to detect these signals.

Electret condenser microphones, commonly used in consumer electronics, are generally sensitive to humidity and heat. (*Figure 1 and Figure 2*) This sensitivity can lead to performance degradation and reliability issues in harsh environments, making them unsuitable for defense applications. In military settings, where equipment must endure extreme temperatures and moisture levels, the fragility of these microphones poses a significant risk. Therefore, more robust alternatives designed to withstand challenging conditions are preferred for defense use, ensuring consistent functionality and durability in the field. Furthermore, microphones designed for consumer electronics are typically obsolete within years from their introduction, making it difficult to maintain a defense application with an expected lifetime of more than 10 years.

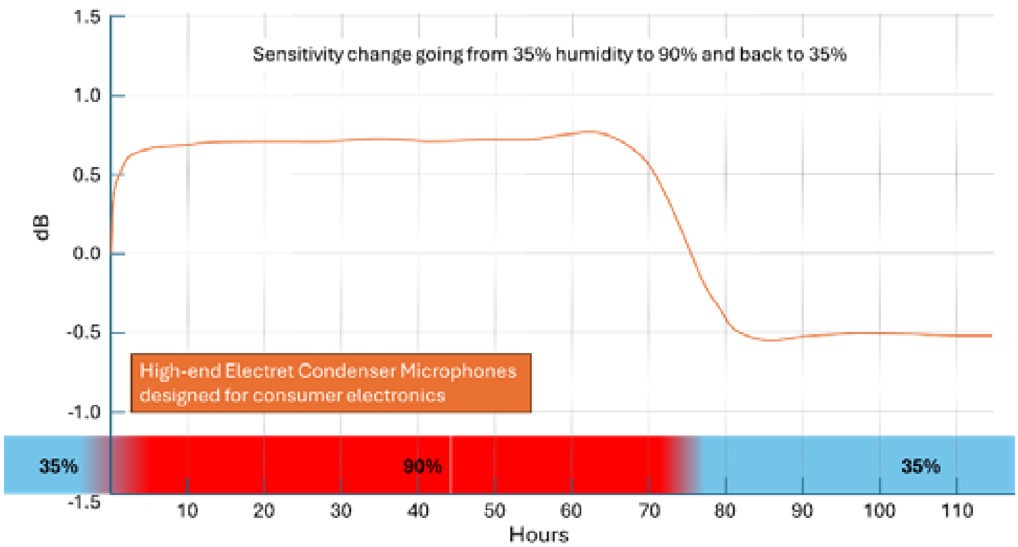


Figure 1 – Typical Sensitivity change for a High-end Electret Condencer Microphone - humidity exposure

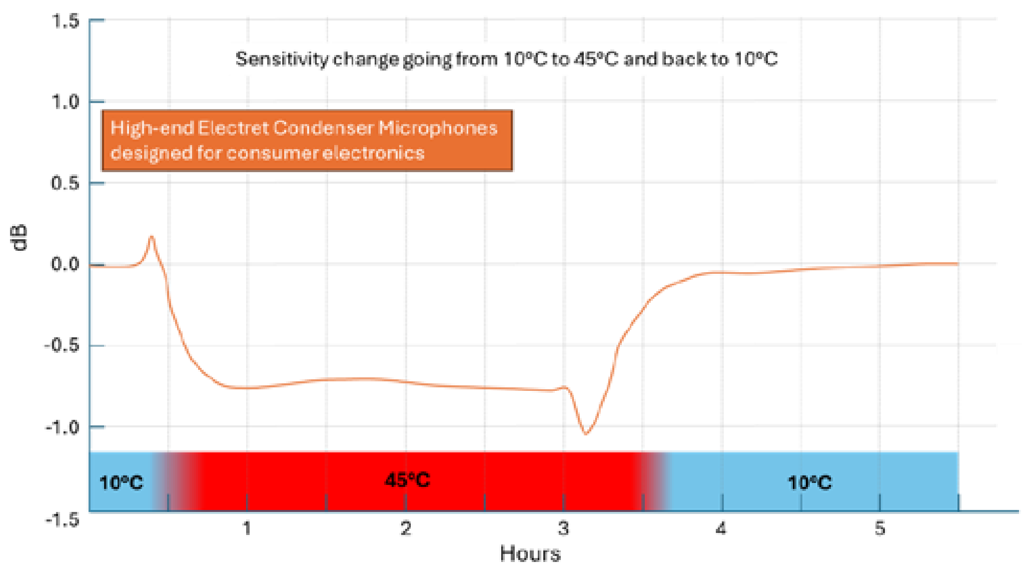


Figure 2 - Typical Sensitivity change for a High-end Electret Condencer Microphone - temperature exposure

Condenser measurement microphones typically have a higher dynamic range and a wider frequency response, making them better suited for capturing nuanced sounds, which is crucial in tactical situations. The wider dynamic range allows them to capture both low and high sound pressure levels (SPL) without distortion, which is vital in varied battlefield conditions. It is also an advantage that condenser microphones can be customized mechanically as well as customized/optimized for specific key parameters.

Evaluating the environmental performance and durability of condenser microphones according to MIL-STD-810 standards is of essence as the battlefield environment is challenging. Different weather conditions such as rain, snow, fog, extreme temperatures, and wind can impact the efficiency of acoustic battlefield systems, as well as vehicle vibrations and shock during transportation. MIL-STD-810 provides a comprehensive framework for testing military equipment under various environmental conditions, ensuring that it meets the rigorous demands of military operations. Adherence to this standard helps enhance the reliability and effectiveness of equipment in the field.

2. MIL-STD-810 Overview

MIL-STD-810 is a military standard developed by the U.S. Department of Defense (DoD) that outlines testing methods for evaluating the environmental and durability characteristics of equipment and systems. The primary goal is to ensure that military equipment can withstand the harsh conditions encountered in various operational environments.

The purpose of the standard is:

- To establish uniform testing procedures for military equipment to assess its performance under realistic environmental stresses.
- To ensure reliability, durability, and operational readiness in diverse conditions.

In MIL-STD-810G, "tailoring" refers to the process of customizing environmental testing requirements to meet the specific needs and operational conditions of a particular system or equipment. This approach acknowledges that not all military equipment will face the same environmental challenges, so it allows for flexibility in testing protocols.

The tailoring for condenser measurement microphones (IEC 61094) will typically apply to the following tests/exposures:

- Solar Radiation
- Blowing Rain
- High & Low Temperature - Storage
- High & Low Temperature - Operational
- Humidity - Operational
- Thermal Shock
- Blowing Dust & Blowing Sand
- Ground Vehicle Vibration – Low & High Band
- Shock - Functional
- Shock - Crash Safety

3. Methodology

The Equipment Under Test, EUT, was 4 pcs. of GRAS 46BE 1/4" CCP Free-field Microphone Set. The microphones have been slightly modified with a special protection grid to provide better rain protection and a slightly modified vent system. Three of the microphones were mounted in a horizontal position under the tests and one single microphone was mounted vertically to test the microphones in different mounting configurations. (*Figure 3*) All microphones were equipped with a nano-coated windscreen.

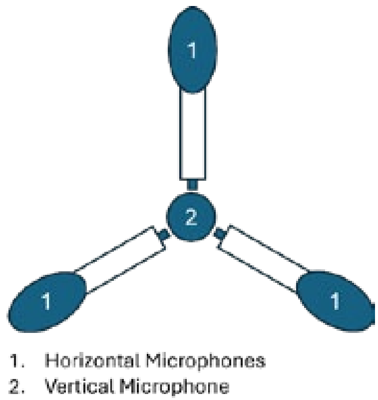


Figure 3 – Microphone mounting

The 46BE microphone is designed to measure high sound pressure levels up to 160 dB and to cover a very wide frequency range (4 Hz to 80 kHz), making it suitable for multiple battlefield applications such as gunshot triangulation and drone detection.

We decided that all relevant tests should be performed consecutively (*Figure 4*) and that the microphones should be calibrated (accredited) before the test campaign and after. We also decided to measure the microphone sensitivity prior to (in-going) and after each individual test (out-going).

Sensitivity can change due to variation in environmental conditions and by physical damage to the microphone. Monitoring any change in sensitivity helps in understanding how these factors affect performance.

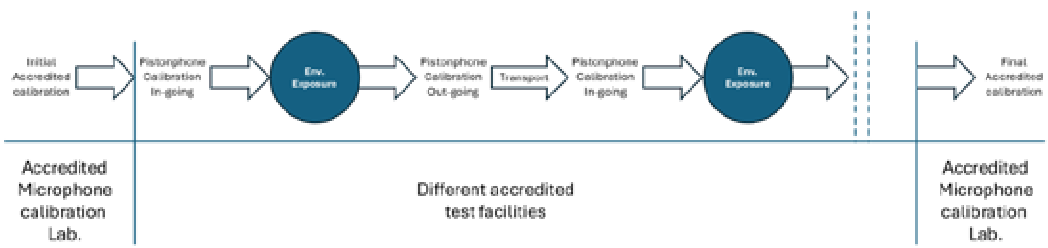


Figure 4 – Consecutive test sequence

Solar Radiation – *MIL-STD-810G:2014, Method 505.6, Procedure II, Figure 505.6-II*

The EUT was exposed partially to solar radiation 20 h per 24 h. A part of the windscreen was outside the solar radiation exposure, so that the evaluation after completion of the test could show if the exposure had any effect.

Blowing Rain – *MIL-STD-810G:2014, Method 506.5, Procedure I*

The EUT was exposed to a water density of 1.7 mm/min with a wind velocity of 64 km/h (17.7 m/s) for 30 minutes. The test was repeated multiple times to expose all sides of the EUT.

High & Low Temperature - Storage - *MIL-STD-810G:2014, Method 506.6, Procedure I*

The EUT was placed in a climate chamber with a constant temperature of +71°C for 2 hours and -40°C for 4 hours. A functional test of the EUT was performed after each temperature exposure.

High & Low Temperature - Operational - *MIL-STD-810G:2014, Method 501.6, Procedure II*

The EUT was placed in a climate chamber with a constant temperature of +60°C for 2 hours. During the last hour of temperature exposure, a functional test was performed. The EUT was then placed in a climate chamber with a constant temperature of -30°C for 2 hours. During the last hour of the temperature exposure, a functional test was performed.

Humidity - Operational - *MIL-STD-810G:2014, Method 507.6, Procedure II - Aggravated*

The EUT was exposed to a humidity level of 95% rh ± 3% rh for a period of 240 hours (10 days). Functional tests were performed on day 5 and on day 10.

Thermal Shock - *MIL-STD-810G:2014, Method 503.6, Procedure I-D*

The EUT was exposed to multi-cycle temperature shocks at constant extreme temperatures. Two climatic chambers were set to -30°C and +60°C respectively. The EUT was then exposed to each constant temperature for 3 hours, being transferred from cold to hot and from hot to cold.

Blowing Dust & Blowing Sand - *MIL-STD-810G:2014, Method 510.6, Procedure I and II*

The EUT was placed 300-500 mm from the front of a duct facing directly into the air stream. For the dust test (*Figure 5*), a concentration of 10.6 ± 7 g/m^3 of Arizona Road Dust is blown with an air speed of 8.9 m/s at a temperature of +70°C for 6 hours – the Arizona Road Dust contains a range of particle sizes, with a significant proportion being very fine particles (less than 10 micrometers) that can easily penetrate equipment.

For the sand test, a concentration of 2.2 ± 0.5 g/m^3 of Arizona Fine Sand is blown with an air speed of 18 m/s at a temperature of +70°C for 1,5 hours – the Arizona Fine Sand typically has a fine grain size, with particles ranging from 0.15 mm to 0.85 mm (150 to 850 micrometers). This fine texture allows it to mimic the dust and sand found in arid regions.

Figure 5 – Dust Test

Ground Vehicle Vibration – *MIL-STD-810G:2014, Method 514.7, Procedure I*

The EUT was mounted on an electrodynamic shaker (*Figure 6*) and was randomly vibrated at a level of 2.24 g_{rms} in each of 3 axes, 6 hours in total.

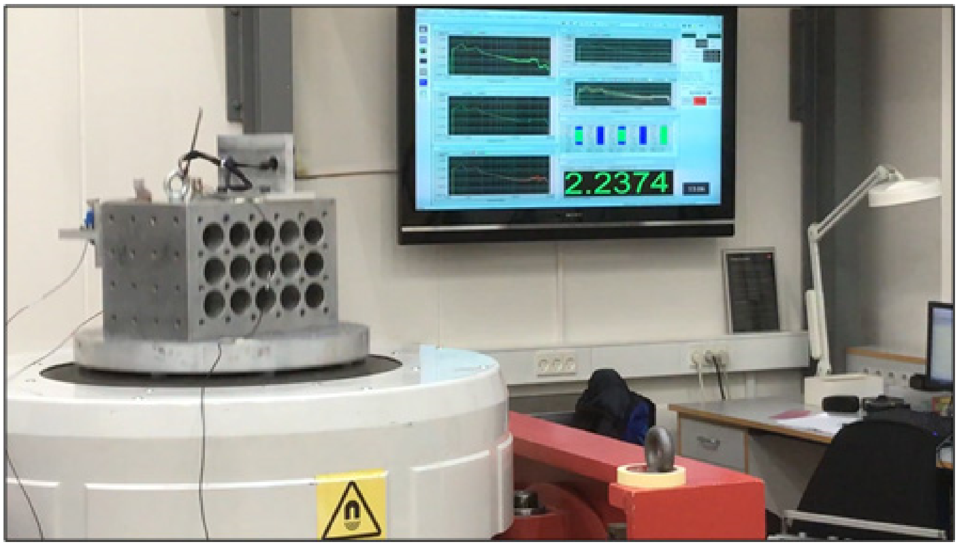


Figure 6 - Ground vehicle vibration

Shock - Functional – *MIL-STD-810G:2014, Method 516.7, Procedure I*

The EUT was mounted in a shock test system. Peak acceleration was 40 g and the sawtooth pulse duration was 11 ms. The EUT was exposed for 18 shocks, 3 in each of 6 directions. A functional test of the EUT was performed during the shock testing.

Shock Crash Safety – *MIL-STD-810G:2014, Method 516.7, Procedure V*

The EUT was mounted in a shock test system. Peak acceleration was 75 g and the sawtooth pulse duration was 6 ms. The EUT was exposed for 12 shocks, 2 in each of 6 directions.

4. Results

The objective of the tests was to ensure the accuracy and reliability of the microphones before and after exposure to environmental stressors. The test period was 6 months. A pre-test in an accredited microphone calibration laboratory was performed prior to the commencement of the MIL-STD-810G tests, on all 4 microphones. The uncertainty for the accredited calibration at 250 Hz was ± 0.08 dB.

Following the completion of the test campaign, the microphones underwent a second round of accredited calibration. This post-test calibration was conducted under the same controlled conditions as the pre-test calibration to ensure consistency.

The MIL-STD-810G testing was performed in different accredited laboratories in different countries in Europe (Denmark, United Kingdom, and Finland). All microphones have been transported as hand luggage to keep the EUT in a controlled environment between the different tests.

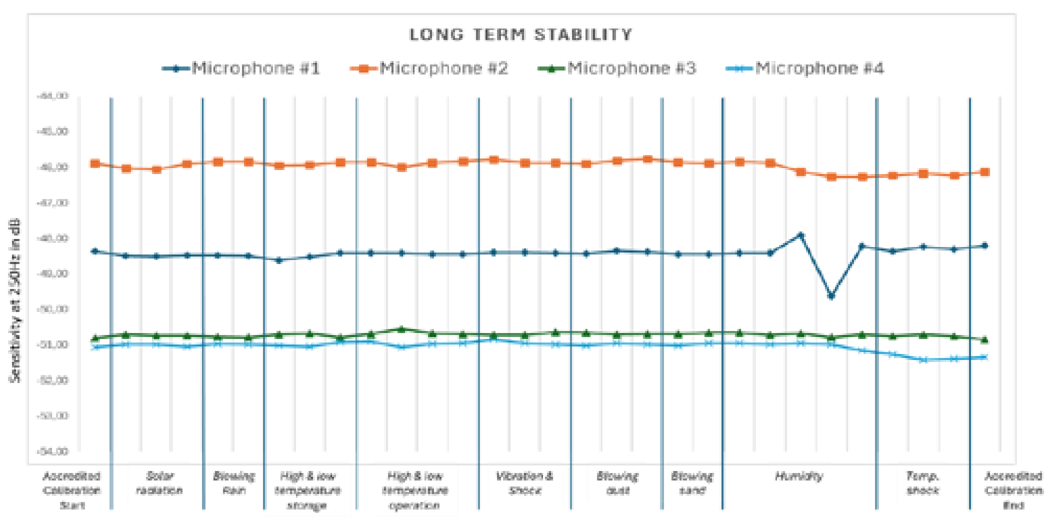
The sensitivity measurements indicated that all microphones remained within a deviation of ±0.3 dB (*Table 1*) from their initial calibrated values. This result demonstrates excellent performance, confirming that the microphones maintained their sensitivity despite exposure to rigorous environmental conditions.

Microphone Number	**Before Test Campaign**	**After Test Campaign**	**Change**
Mic. #1	-48,37 dB	-48,21 dB	0,16 dB
Mic. #2	-45,89 dB	-46,12 dB	-0,23 dB
Mic. #3	-50,80 dB	-50,85 dB	-0,05 dB
Mic. #4	-51,07 dB	-51,34 dB	-0,27 dB

Table 1 - sensitivity analysis of microphones used in a series of MIL-STD-810G tests conducted from July to December

Furthermore, the microphones were calibrated multiple times using GRAS 42AP Intelligent Pistonphone Class 0 during the 6-month test period. The sensitivity was measured and documented prior to all subtests and after all subtests.

The sensitivity measurements were conducted in-situ, utilizing a pistonphone. While this method allowed for real-time assessment under operational conditions, it is important to note that the uncertainty associated with this approach is inherently larger (± 0.2 dB) than that of an accredited calibration performed in a controlled laboratory environment.



Graph 1 - Long Term Stability for all 4 microphones over the 6 months test campaign. Each datapoint represents a sensitivity test before, during or after a subtest.

The sensitivity measurements before and after the subtests (*Graph 1*) exhibited excellent consistency, remaining within a very narrow tolerance range. Despite the larger uncertainty associated with the in-situ testing method using a pistonphone, the results affirm the robustness and reliability of the microphones.

Microphone #1 shows some change in sensitivity during the aggravated humidity test (10^{th} cycle) at 250 Hz. A deviation of 1 dB was measured. This could indicate that some moisture has penetrated the microphone, slightly degrading its performance. However, the microphone showed no long-term degradation as the sensitivity came back to nominal levels after the test.

This result demonstrates excellent performance, both for long term performance and for shorter time, confirming that the microphones maintained their sensitivity and consequently their overall performance, despite exposure to rigorous environmental conditions.

5. Discussion

Blowing rain occurs when strong winds drive water droplets against the microphone system, potentially saturating the foam that protects the microphone from the wind.

The windscreen surrounding the microphone is designed to minimize wind noise affecting the microphone diaphragm (*Figure 7*). When exposed to blowing rain, this foam can become soaked, which may compromise its ability to effectively dampen wind noise. As a result, the quality of sound captured by the microphone may degrade, leading to erroneous results.

However, replacing the windscreen or waiting for drier conditions will mitigate these effects. Importantly, the resilience of the microphone ensures that it will continue to operate effectively, regardless of the weather conditions affecting the foam.

It was also observed that the windscreen did not provide full protection against blowing dust and sand. The windscreen is porous as it must be almost acoustically transparent. It is therefore not possible to avoid residues of dust and sand inside the windscreen. Replacing or cleaning the windscreen after convoy driving in dusty environments is recommended.

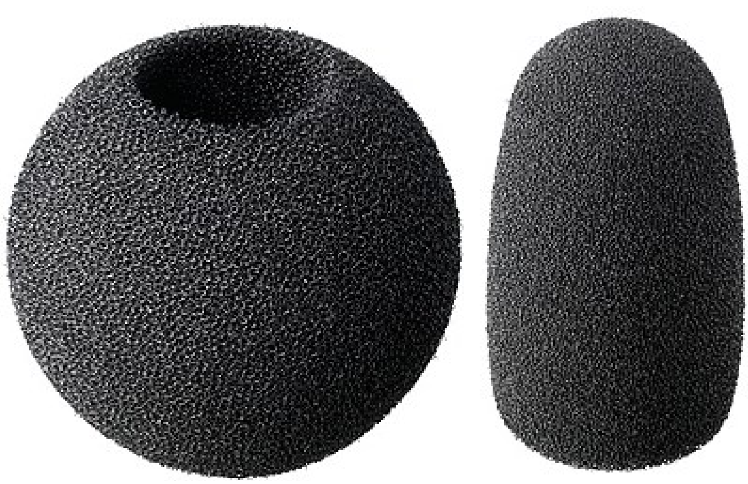


Figure 7 – Nano-coated polyurethane foam used for windscreens

It is recommended that more research is done on the development of a windscreen system able to resist water, sand, and dust. Some possible ideas are:

- Improved hydrophobic foam (water-repellent) materials for windscreens and microphone protection to ensure that the foam does not become saturated.
- Improved dust-resistant foam that has been treated to resist dust accumulation, maintaining its effectiveness over time.

6. Conclusion

The accredited calibration of microphones before and after the MIL-STD-810G test campaign ensured reliable performance and accuracy. The change in sensitivity within ±0.3 dB for all four microphones indicates that the microphones performed exceptionally well, validating their robustness and suitability for use in harsh environments over a long period of time.

Furthermore, all tests, performed in-situ with a pistonphone in between the accredited calibrations, showed only a minimal deviation. This indicates that the condenser measurement microphone performed exceptionally well, not only over a long period, but also under and after every sub-test.

7. References

- MIL-STD-810G, 31 October 2008, Department of Defense, Test Method Standard – Environmental Engineering Considerations and Laboratory Tests
- Product Information - GRAS 46BE 1/4" CCP Free-field Standard Microphone Set (https://www.grasacoustics.com/?eID=1709645390&product=7)
- Product Information - GRAS 42AP Intelligent Pistonphone Class 0 (https://www.grasacoustics.com/?eID=1709645390&product=88)

8. Acknowledgments

- BOGHOLM Consulting AB

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