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ISO 5305

Noise measurements for UAS (unmanned aircraft systems)

Mesures de bruit pour les UAS (aéronefs sans pilote)

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Foreword

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 16, *Unmanned aircraft systems*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Within the last decade, multirotor unmanned aircraft systems (UAS) have greatly impacted the global market with unique and cost-effective vehicle systems for photography, industrial surveying, logistics, modern agricultural, civil engineering inspection, etc. A UAS can exert a significant impact on the living environments of the human and wildlife during its operation at low altitudes. The adverse environmental impacts include UAS noise. In urban applications, the UAS noise can be more annoying than road traffic or aircraft noise at similar noise levels[1].

The characteristics of UAS noise vary in different operating conditions. The modern agricultural UAS are designed to operate at a few meters above ground level. The logistic UAS are operated mainly in cruise conditions. The UAS for civil engineering inspection may operate in both hover and cruise conditions. The flight conditions of UAS are different from large civil transport aircraft and traditional rotorcraft[2]. Therefore, the noise characteristics are perceived differently, making the existing noise test codes used for large aircraft, helicopter, and tilt-rotor vehicles unsuitable. These test codes were developed for aircraft that typically operate far above civilians and urban regions, which are remotely related to the multirotor UAS. Currently, there is no internationally agreed procedures for measuring UAS noise in different working conditions.

The recently published European Commission Delegated Regulation EU 2019/945[3] for UAS details a noise test code following ISO 3744[4]. The EU 2019/945 considers UAS with maximum take-off mass (MTOM) up to 25 kg. The test code measures the sound power level of UAS in indoor and outdoor environments. The regulation was later amended by EU regulation 2020/1058 [5] as regards new UAS classes. However, the measurement is limited only to the UAS in hover. In addition, the microphone arrangement is not specified to avoid the influence of unsteady aerodynamic flow induced by the UAS on the acoustic measurement. Also, the directional nature of the noise produced by UAS was not considered. Recently, a guidance on the noise measurement of UAS lighter than 600 kg was published by EASA[6].

This document specifies the noise measurement methods for multirotor-powered UAS with an MTOM less than 150 kg. The noise due to the multirotor-powered UAS contains both tonal and broadband content, both of which may have a significant impact on humans. The tonal noise can cause annoyance because humans are sensitive to pitch characteristics[7], while the broadband noise can affect the human brainstem auditory evoked response[8]. Both the tonal and broadband noise produced by multirotor-powered UAS is dependent on the working conditions, leading to significant differences at different microphone locations.

This document aims at characterizing the UAS noise in different working conditions, but the efforts are left to the manufactures or client requirement to decide the needed measurements. It is not necessary to perform all measurements, and the measurer should select the measurement method according to the purpose. It provides procedures for performing noise measurements at the typical UAS flight-phases including hover, take-off, landing, and cruise. Configurations of the microphones are specified to ensure measurements are made at different locations to quantify the directivity of UAS noise. It also specifies the requirements of how measurements are conducted with the acoustic far-field conditions satisfied. This document focuses on the methods of measuring the sound pressure signals of the UAS under different working conditions, based on which post-processing of the recorded data can be conducted. For example, by computing the narrow-band noise spectra, the tonal noise components can be extracted. However, requirements for signal processing and evaluation of the measured data are not specified in this document. Instead, depending on the test condition, several common noise metrics are recommended, and the procedures to compute these metrics based on the recorded data are given in Annex A. This document can promote the understanding of the noise characteristics of UAS and provide reference methods for both manufacturers and regulatory bodies to assess the UAS noise.

Noise measurements for UAS (unmanned aircraft systems)

1 Scope

This document specifies methods for recording the time history of instantaneous sound pressure in several positions around rotor powered unmanned aircraft systems (UAS) with a maximum take-off mass (MTOM) of less than 150 kg in accordance with ISO 21895[9]. The UAS can be either electrically powered or fuel-powered. It is not applicable to the tilt-rotor or tilt-wing UAS. It does not account for the UAS noise certification or regulation

This document can also be applied to measure the sound pressure from a UAS with either multiple rotors or a single rotor.

This document specifies:

a) recommendations and requirements for three different test facilities for the noise measurements of various categories of multirotor-powered UAS:

— requirements and recommendations of UAS noise tests in anechoic chambers (Clause 7);

— requirements and recommendations of UAS noise tests in anechoic wind tunnels (Clause 8);

— requirements and recommendations of UAS noise tests in outdoor environments (Clause 9);

b) requirements and recommendations for the configuration of noise measurement for multirotor-powered UAS in hover, vertical take-off and landing, and horizontal cruise;

c) recommendations for the test configuration and procedures to minimize the influence of meteorological effects.

2 Normative reference documents

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 26101-1, *Acoustics — Test methods for the qualification of the acoustic environment — Part 1: Qualification of free-field environments*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

IEC 60942, *Electroacoustics — Sound calibrators*

IEC 61094-4, *Electroacoustics — Measurement microphones – Part 4: Specifications for working standard microphones*

IEC 61260-1, *Electroacoustics — Octave-band and fractional-octave-band filters - Part 1: Specifications*

IEC 61672-1, *Electroacoustics — Sound level meters – Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
anechoic chamber
test room in which a free sound field is obtained

[SOURCE: ISO 3745:2012[10], 3.7, modified — The admitted terms have been removed.]

3.2
anechoic wind tunnel
wind tunnel enclosed in an *anechoic chamber* (3.1) for indoor testing

Note 1 to entry: It has sufficiently low *background noise* (3.3) and the reflection of the sound from the test section is minimized.

3.3
background noise
noise from all sources other than the noise source under test

Note 1 to entry: Background noise also includes the airborne noise, structure-borne noise and electrical noise in the instrumentation.

3.4
sound pressure
p
difference between an instantaneous total pressure and the corresponding static pressure

Note 1 to entry: Sound pressure is expressed in pascals (Pa).

3.5
A-weighted sound pressure level
$L_{p,\mathrm{A}}$
ten times the logarithm to the base 10 of the ratio of the square of A-weighed frequency-band-limited sound pressure p to the square of the reference pressure of p_0=20 µPa

$$L_{p,\mathrm{A}} = 10 \log_{10} \left(\frac{p_\mathrm{A}^2}{p_0^2} \right)$$

Note 1 to entry: See the definition for "sound pressure level" in ISO/TR 25417[11].

Note 2 to entry: The frequency band shall be reported.

3.6
slow time-weighted A-weighted sound pressure level
$L_{p,\mathrm{A,S}}$
ten times the logarithm to the base 10 of the ratio of the running time average of the time weighted square of the A-weighted frequency-band-limited sound pressure to the square of the reference pressure of p_0=20 µPa

$$L_{p,\mathrm{A,S}}(t) = 10 \log_{10} \left(\frac{\left(\frac{1}{\tau_\mathrm{s}} \right) \int_{t_0}^{t} p_\mathrm{A}^2(\xi) e^{-\frac{t-\xi}{\tau_\mathrm{s}}} \mathrm{d}\xi}{p_0^2} \right)$$

where

τ_s = 1 s is the exponential time constant for the slow time weighting;

t_0 is the starting time;

t is the time

[SOURCE: IEC 61672-1: 2013, 3.6, modified — Only applies to the slow time weighting.]

3.7
maximum slow time-weighted A-weighted sound pressure level
$L_{p,\mathrm{A,Smax}}$
greatest slow time-weighted A-weighted sound pressure level within a stated time interval

[SOURCE: IEC 61672-1: 2013, 3.7, modified — Only applies to the slow time weighting.]

3.8
A-weighted sound exposure
$E_{\mathrm{A},T}$
integral of the square of A-weighted frequency-band-limited sound pressure p_A over a stated time interval or event of duration T (starting at t_1 and ending at t_2)

$$E_{\mathrm{A},T} = \int_{t_1}^{t_2} p_\mathrm{A}^2(t)\mathrm{d}t$$

Note 1 to entry: The frequency band and frequency resolution shall be reported.

Note 2 to entry: See the definition for "sound exposure" in ISO/TR 25417[10].

3.9
A-weighted sound exposure level
$L_{E,\mathrm{A},T}$
ten times the logarithm to the base 10 of the ratio of the sound exposure, $E_{\mathrm{A},T}$, to a reference value $E_0 = 4\times10^{-10}$ Pa^{2}s

$$L_{E,\mathrm{A},T} = 10\log_{10}\left(\frac{E_{\mathrm{A},T}}{E_0}\right)$$

3.10
nominal height
target height of the *unmanned aircraft system (UAS)* (3.16) under test

3.11
hover
operation condition of an *unmanned aircraft system (UAS)* (3.16) that the vertical and horizontal positions and orientation are relatively unchanged

3.12
yaw
operation condition of an *unmanned aircraft system (UAS)* (3.16) that the vertical position is relatively unchanged, while the UAS is rotating with respect to the vertically oriented axis

3.13
take-off
operation condition of an *unmanned aircraft system (UAS)* (3.16) that the height is kept increasing

Note 1 to entry: In this document, it is restricted to vertical motion and the speed is constant except for the initial acceleration process.

3.14
landing
operation condition of an *unmanned aircraft system (UAS)* (3.16) that the height is kept decreasing

Note 1 to entry: In this document, it is restricted to vertical motion and the speed is constant except for the final deacceleration process.

3.15
cruise
operation condition of an *unmanned aircraft system (UAS)* (3.16) that moves unidirectionally at a fixed height

Note 1 to entry: In this document, it means that the speed is constant.

3.16
UAS
unmanned aircraft system
aircraft and its associated elements which are operated remotely or autonomously

Note 1 to entry: In this document, it refers to the vehicles equipped with single or multiple rotors.

Note 2 to entry: This document is not valid to the tilt-rotor or tilt-wing UAS.

3.17
UAS diameter
D_A
unmanned aircraft system diameter
diameter of the smallest cylinder that encompasses the projection shape of the *unmanned aircraft system (UAS)* (3.16) on a plane

3.18
UAS centre
unmanned aircraft system centre
centre of the cylinder that encompasses the projection of the *unmanned aircraft system (UAS)* (3.16) shape on a plane

3.19
propeller diameter
D_R
diameter of each propeller employed for the multi-propeller powered *unmanned aircraft system (UAS)* (3.16)

Note 1 to entry: A schematic of D_A and D_R is shown in Figure 1.

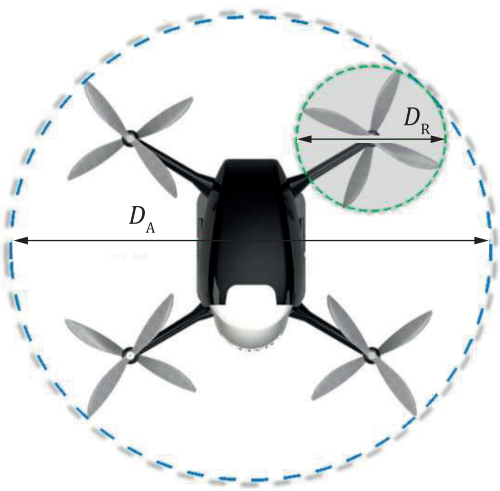


Figure 1 — A schematic of UAS diameter D_A and propeller diameter D_R

4 Abbreviated terms

MTOM	maximum take-off mass
PSD	power spectral density
RPM	revolution per minute

5 Instrumentation

5.1 General

The instruments shall record the time history of measured instantaneous sound pressure signals in the frequency range from 20 Hz to 20 kHz. The sound pressure data shall be stored as digital information in a non-compressed file format at a sampling frequency of at least 48 kHz.

For measurements in anechoic chambers and anechoic wind tunnels as described in this document, the microphones shall be either free-field microphone type WS2F or WS3F as defined in IEC 61094-4.

For outdoor measurements using ground boards as described in this document, the microphones shall be pressure microphones type WS2P or WS3P as defined in IEC 61094-4.

The instruments for measuring sound pressure signals, including microphone(s) as well as cable(s), windscreen(s), recording devices, and other accessories, if used, shall meet the relevant requirements for a class 1 instrument according to IEC 61672-1, as appropriate over the range of meteorological conditions specified in the method. Filters shall meet the requirements for a class 1 instrument according to IEC 61260-1.

5.2 Calibration

Before and after the measurements, a sound calibrator meeting the requirements of IEC 60942 class 1 shall be applied to each microphone to verify the calibration of the entire measuring system at one or more frequencies within the frequency range of interest. Without any adjustment, the difference between the readings made before and after each series of measurements shall be less than or equal to 0,5 dB. If this value is exceeded, the results of the series of measurements shall be discarded.

The calibration of the sound calibrator, the conformity of the instrumentation system with the requirements of IEC 61672-1 and the conformity of the filter set with the requirements of IEC 61260-1 shall be verified at intervals in a laboratory making calibrations traceable to appropriate standards.

The sound calibrator should be calibrated at intervals not exceeding 1 year; the conformity of the instrumentation system with the requirements of IEC 61672-1 should be verified at intervals not exceeding 1 year; and the conformity of the filter set with the requirements of IEC 61260-1 should be verified at intervals not exceeding 1 year.

6 General requirements

6.1 General

The characteristics of UAS noise shall be addressed in the measurements.

a) The condition of noise measurements shall satisfy the far-field condition.

b) The UAS noise is directional, and the sound pressure at different locations shall be measured.

c) The unsteady aerodynamic flow induced by the UAS rotors can affect the noise measurements if impinging to the microphones. Therefore, aerodynamic requirements on the measurement locations are specified in 6.3.

The tests can be conducted in either an anechoic chamber, an anechoic wind tunnel or outdoors, depending on the MTOM, size and flight speed of the UAS. The measurement requirements in the anechoic chamber, anechoic wind tunnel and outdoor tests are specified in Clause 7, Clause 8 and Clause 9, respectively.

NOTE This document focuses on methods to record the sound pressure signals in both indoor and outdoor tests. Requirements and recommendations in different facilities are provided, but the selection of the facility is not compulsorily specified.

6.2 Requirements of acoustic far-field condition

The far-field condition is dependent on the properties of noise sources, including frequency, and the spatial distribution of the noise source (including its size). When the far-field condition is satisfied, the noise level decreases inversely with the microphone distance, and the UAS noise can be characterized by acoustic directivity. Therefore, there is a requirement for a minimum distance between the UAS and the microphones, which depends on the size of the UAS. For UAS noise measurements, to ensure the acoustic far-field condition, the microphone distance R shall be at least $5D_A$, i.e.

$$R \geq 5D_A \quad (1)$$

For sound at a high frequency, the significant interference pattern can affect the validity of the far-field condition proposed in Formula (1). However, the effect can be minimized when summing in a frequency band, for example, a 1/3-octave band, is performed. An illustration of the validity of the far-field condition using numerical experiments is given in Annex B. An experimental measurement of the acoustic far-field condition for a UAS propeller in an anechoic chamber following ISO 26101-1 is given in Annex C.

6.3 Requirements of position of UAS to reduce aerodynamic flow effect

To avoid an aerodynamic ground effect on the UAS propellers, the height of the UAS to the ground shall be at least the maximum of $H_s = 1{,}2$ m and $2D_A$, where D_A is the UAS diameter.

$$H_0 \geq \max(2D_A, H_s) \quad (2)$$

NOTE 1 The aerodynamic ground effect for propellers was described by Betz in the 1930s[12].

NOTE 2 The height of UAS refers to the height of UAS centre to ground.

6.4 Requirements of position control

6.4.1 General

The variation in the position of the UAS can lead to noise measurement uncertainties. The location of the UAS shall be recorded with the measurement error within 3 %. The orientation angle of the UAS shall be recorded with a measurement error within 3°.

NOTE 1 The requirements in this subclause only apply for UAS in flight conditions. For wind tunnel tests, the UAS is mounted at fixed locations.

NOTE 2 For flight conditions, this document only considers unidirectional motion at constant speed.

6.4.2 Requirement of position accuracy

For the UAS in hover and yaw, during the measurement period (at least 20 s), the deviation of the UAS position shall be within $\pm 5\,\%$ of the shortest distance between UAS and microphone. For example, if the shortest observer distance is taken as $R = 5D_A$, the requirement for the deviation of UAS position shall be $|\Delta \boldsymbol{y}| \leq 0{,}25D_A$ during the measurement, where $\boldsymbol{y}$ is the coordinate of the UAS centre from the closest microphone position.

For the UAS in the take-off and landing conditions for anechoic chamber tests, during the measurement period (at least 5 s), the position accuracy in the lateral direction shall be within $0{,}1L$, where L is the distance of the target UAS path to the lateral microphones (see Figure 5). For outdoor tests, the position accuracy in the horizontal direction shall be within $0{,}1H$, where H is the height of the centre of the UAS above the ground at the mid-point of the flight path.

For the UAS in the cruise condition in anechoic chamber tests, during the measurement period (at least 5 s), the position accuracy of the lateral location shall be within $0{,}1L$, where L is the lateral distance of the target UAS to the lateral microphones. The accuracy in the vertical direction shall be within $0{,}1H$, where H is the nominal height of the UAS.

For outdoor tests, the location of the centre of the UAS shall be determined to be within $0{,}1H$ in the vertical direction and within $0{,}1H$ to the target flight path in the lateral direction, where H is the nominal height of the centre of the UAS above the ground during the cruise.

6.4.3 Requirement of speed accuracy

For the tests of UAS in take-off, landing and cruise, the speed of the UAS shall have reached the target operation speed at the middle point of the flight path. The deviation of the UAS speed at the middle point of the flight path shall be within $\pm 5\,\%$ of the target operation speed.

6.5 Requirements of background noise

During the measurements, the A-weighted sound pressure level $L_{p,\mathrm{A}}$ of the UAS noise shall be sufficiently higher than that of the background noise. The frequency band used to compute $L_{p,\mathrm{A}}$ shall be reported. The procedures to compute the sound pressure level in different frequency bands are given in Annex A.

In tests in anechoic chambers and anechoic wind tunnels, $L_{p,\mathrm{A}}$ of the background noise at the microphone locations shall be at least 6 dB, preferably more than 15 dB, below the corresponding sound pressure level of the measured UAS noise.

If the 6-dB criterion is not satisfied, data may still be taken and reported, but the accuracy of the results can be reduced. In this case, the frequency ranges that do not satisfy the background noise requirement shall be clearly stated.

In outdoor tests, at the measurement positions, the background noise (including wind noise at the microphones) measured in each of the frequency bands of interest shall be at least 6 dB below the uncorrected level of the source measured in the presence of this background noise. In practice, suitable windscreens are needed to meet the signal to noise ratio requirement.

7 Anechoic chamber tests

7.1 General

Tests using an anechoic chamber can provide a controllable condition for noise measurements of UAS at different flight conditions.

However, the finite size of the anechoic chamber can limit the size and operation speeds of the UAS. This document specifies the requirements for the anechoic chamber and the details of noise measurement.

NOTE The anechoic chamber tests are often applicable to light and small UAS, for example, with the MTOM less than 4 kg.

For UAS with MTOM ranges from 4 kg to 25 kg, anechoic chamber tests are also suitable once the requirements for far-field conditions, aerodynamic flow effects and clearance distances are met. Otherwise, the tests should be conducted in either wind tunnels or the outdoor environment.

Environmental conditions having an adverse effect on the microphones used for the measurements, for example, strong electric or magnetic fields, high or low temperatures, high humidity, shall be avoided. The instructions of the manufacturer of the measuring instrumentation regarding adverse environmental conditions shall be followed.

7.2 Requirements of anechoic chamber

7.2.1 Size

The anechoic chamber shall provide sufficient space for noise measurements of UAS. The distance can be influenced by the requirements on the distances between the UAS to microphones, UAS to walls, floor, and ceiling (or wedge tips if there are wedges) in the anechoic chamber, the UAS operation distance, and the microphone distance to the walls, floor, and ceiling (or wedge tips).

7.2.2 Anechoic chamber qualification

The validity of the inverse square law defined in ISO 26101-1 shall be ensured for all source positions and measurement directions specified in this document.

The maximum allowed deviation from the inverse square law in any of the measured directions for any of the microphone positions shall not exceed the values given in Table 1.

Table 1 — Maximum allowed deviation from the inverse square law for anechoic chamber qualification.

One-third-octave mid-band frequency (Hz)	Allowable deviation (dB)
125 to 630	± 1,5
800 to 5 000	± 1,0
≥6 300	± 1,5

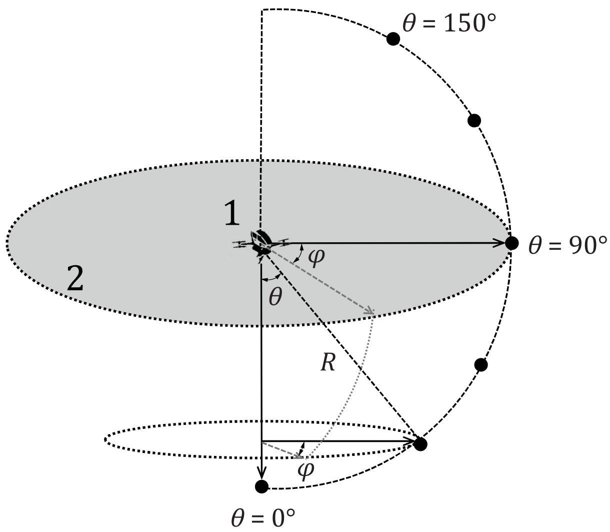
For the source positions (UAS locations) defined in 7.3.2 and 7.3.3, the sound source used in ISO 26101-1 shall be positioned in the positions closest to the wall, floor and ceilings and shall be tested with microphone traverse directions along the measurement directions defined by the microphone positions.

All microphones shall be placed within the region in the anechoic chamber satisfying the qualification. This distance of the microphone to the walls, floor, and ceiling (or the wedge tips) is denoted as H_m.

7.3 Measurement configurations

7.3.1 General

This subclause specifies the requirements of microphone configurations and UAS operation in anechoic chamber tests. The microphones shall be placed on acoustically treated support to minimize reflections. When the location and attitude of the UAS, and the location of a microphone, are fixed, observer angles θ and φ can be determined, a schematic of which is shown in Figure 2.



Key

1 UAS

2 plane of rotation

θ, φ observer angles

R distance of the UAS centre to the microphone

The UAS may be operated in either a hover, yaw, take-off, or landing condition.

Figure 2 — A schematic of the observer angles for UAS noise measurement

Various microphones are needed to measure the directivity of the UAS noise at different observer angles.

— For hover and yaw conditions, θ shall be measured at least from 0° to 150° with a resolution of 30° or smaller. The directions shall be maintained with an accuracy of $\pm 5^\circ$.

— For take-off and landing conditions, θ shall be measured at least from 0° to 90° relative to the middle position of the UAS flight path. The resolution shall be 45° or smaller. The directions shall be maintained with an accuracy of $\pm 5^\circ$.

— For cruise conditions, θ shall be measured at observer angles range from 0° to 135° relative to the middle position of the UAS flight path. The resolution shall be 45° or smaller. The directions shall be maintained with an accuracy of $\pm 5^\circ$.

For hover, take-off, landing and cruise conditions, the directivity of the UAS noise at different φ shall be measured by adjusting the UAS orientation with an angle resolution of 30° or smaller.

In yaw and hover states, the UAS may also be fixed on rigid support to allow for measurements to reduce the variations in UAS position. The support shall be acoustically treated to avoid reflections. In this case, the UAS flight system should be adapted such that the propeller rotation speeds are directly controlled to yield the target thrust.

Multiple microphones are needed to cover the target observer angles. 7.3.2 and 7.3.3 give recommendations of microphone arrangement and measurement procedures by using only 4 microphones and multiple microphones, respectively. During the test, the microphones are installed towards the UAS position.

This document focuses on measuring sound pressure signals, based on which the objective metric(s) can be computed. However, before the measurements, the objective metric(s) and the confidence interval of the metric(s) shall be given to determine the number of repeatability tests.

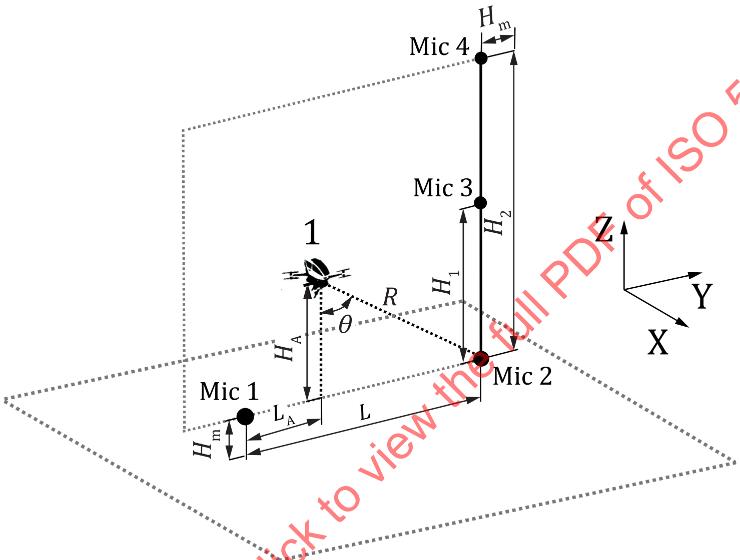
For the noise measurements of UAS in hover and yaw conditions in anechoic chambers, the A-weighted sound pressure level $L_{p,\mathrm{A}}$ should be employed as the noise metrics with a 95 % confidence interval of ±1 dB. Here the confidence level refers to the random uncertainty during the repeatability tests.

For the noise measurements of UAS in take-off, landing, and cruise conditions in anechoic chambers, the A-weighted sound exposure level $L_{E,\mathrm{A},T}$ should be employed as the noise metrics with a 95 % confidence interval of ±1 dB. Here the confidence level refers to the random uncertainty during the repeatability tests.

7.3.2 Hover and yaw: 4-microphone approach

7.3.2.1 UAS position and microphone arrangement

The schematic to measure the UAS noise in hover and yaw is shown in Figure 3. With fixed microphone locations, different observer angle θ can be realized by adjusting the UAS position.



Key

1	UAS
L	horizontal distance of the lateral microphones
L_A	horizontal distance of the UAS to Mic 1
H_A	height of the UAS in hover and yaw conditions
H_1	height of the lateral microphone Mic 3
H_2	height of the lateral microphone Mic 4
H_m	microphone clearance distance to walls and ground
θ	observer angle
R	distance of the UAS centre to the microphone

NOTE The microphone locations can be fixed in the measurement, while the UAS location determined by H_A and L_A can be adjusted in the measurements.

Figure 3 — Schematic of the noise test configuration for UAS in hover and yaw conditions

The measurement uses 4 microphones Mic 1, Mic 2, Mic 3, and Mic 4. The distance (denoted as H_m) from the microphone positions to the wall, floor and ceiling shall be chosen so that each microphone position is within the part of the anechoic chamber where the inverse square law as specified in 7.2.2 is fulfilled. The microphones are installed pointing to the UAS location. The UAS and microphone locations are denoted as below.

— Mic 1 is used as the reference point.

— The UAS has a height of H_A and a lateral distance L_A to Mic 1. To avoid the aerodynamic flow effect, it is required that $H_A \geq \min(2D_A, H_s)$ and $H_s = 1{,}2\,\text{m}$, as specified in 6.3.

— Mic 2 in the lateral direction is $L \geq 5\,D_A$ from Mic 1 to ensure enough space for UAS operation to realize the far-field condition.

— Mic 3 in the lateral direction is L from the Mic 1, and the height is $H_1 = L$.

— Mic 4 in the lateral direction is above Mic 3. It is used to measure the noise above the UAS. The height of Mic 4 is $H_2 = 2L$.

7.3.2.2 Measurement procedure

Measurements shall be conducted for the UAS at different height H_A and lateral distance L_A (see Figure 3) to record the sound pressure of the UAS in hover and yaw conditions. For each UAS location, the equivalent microphone distance observer angle by the i^{th}-microphone are

$$\theta = \tan^{-1}\left(\frac{\Delta Y_i}{\Delta X_i}\right), R = \sqrt{\Delta X_i^2 + \Delta Y_i^2} \tag{3}$$

where ΔX_i and ΔY_i are the coordinate differences between the i^{th}-microphone and the UAS in the X and Y directions, respectively. Therefore, using the 4 microphones, one can determine the UAS location to yield different target equivalent observer angles. An example is given in Table D.1 in Annex D, where 6 UAS positions are tested to yield the equivalent observer angles ranging from 0° to 150°. During the test, the microphones should be equipped with windscreens to reduce the impact of the flows induced by the UAS operation. An example showing the effect of using windscreens for the UAS propeller noise test is given in Annex E.

For all microphones, the far-field condition $R \geq 5D_A$ shall be satisfied, as specified in 6.2. Otherwise, the data obtained cannot be used.

At each configuration, the measurements shall follow the procedures.

a) Operate the fully charged UAS at the specified location within the position accuracy limits specified in 6.4.

b) Conduct the measurement for at least 20 s.

c) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

d) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

In the measurements, the microphone distance R varies in different configurations. Therefore, the sound pressure shall be scaled to the distance of $R_0 = 1$ m. Denoting the measured sound pressure as $p(R,\theta)$, then the scaled sound pressure is:

$$p_c(\theta) = p(R,\theta)\left(\frac{R}{R_0}\right) \tag{4}$$

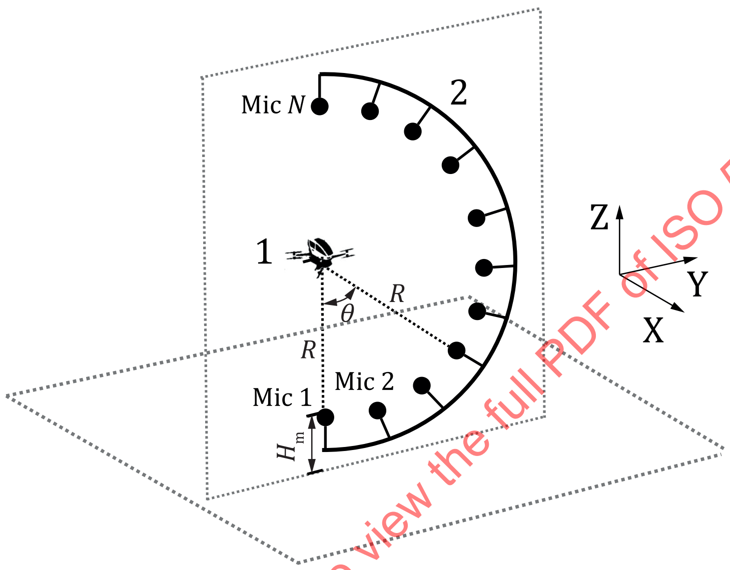
7.3.3 Hover and yaw: multiple microphone approach

7.3.3.1 General

If multiple microphones are accessible, they can be installed on an arc support to simultaneously measure the sound pressures of the UAS at different observer angles.

7.3.3.2 UAS position and microphone arrangement

Figure 4 is a schematic showing an example to measure the sound pressures of the UAS in hover and yaw with multiple microphones. The distance of the UAS to all microphones is $R \geq 5D_A$ to meet the far-field condition specified in 6.2.



Key

1	UAS
2	arc support
N	number of microphones
H_m	microphone clearance distance to the ground
θ	observer angle
R	distance of the UAS centre to the microphone

NOTE The observer angles are evenly ranging from 0° to 180°.

Figure 4 — Schematic of the noise test configuration for UAS in hover and yaw conditions using multiple microphones

The microphones are placed on a structurally rigid arc support coated with sound absorption materials to minimize the sound reflection. The microphones are evenly placed on the arc such that the interval of observer angle is $\Delta\theta = 180^\circ / (N-1)$, where N is the microphone number. More microphones yield finer observer angle resolution. The microphone number is suggested to be larger than 11 to yield the angular interval smaller than 18°.

The UAS is operated at the centre of the arc within the position accuracy limits specified in 6.4. When the sound pressures are recorded, the results shall be scaled to the distance of $R_0 = 1$ m as presented in Formula (4).

7.3.3.3 Measurement procedure

Noise measurements of UAS noise in hover and yaw conditions shall be conducted following the procedures below.

a) Operate the fully charged UAS at the specified location within the position accuracy limits specified in 6.4.

b) Conduct the measurement for at least 20 s.

c) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

d) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

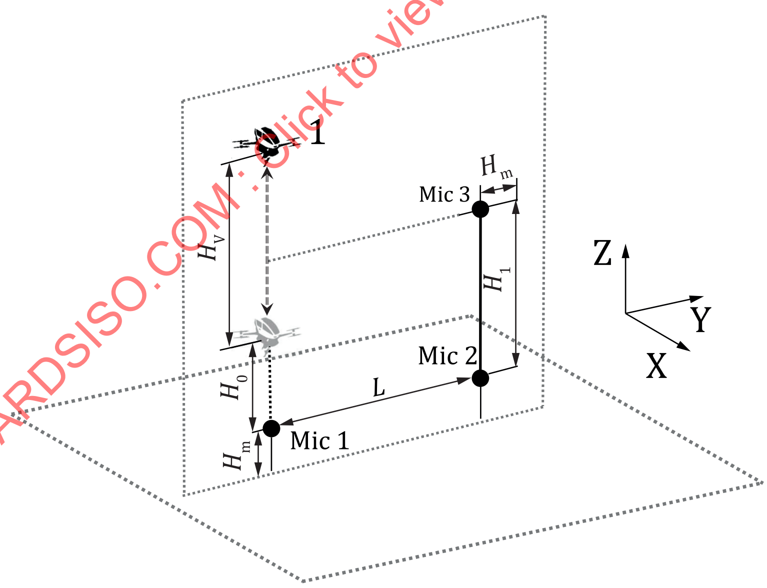
7.3.4 Take-off and landing

7.3.4.1 General

This subclause specifies the requirements of UAS noise measurement in take-off and landing conditions in anechoic chambers. θ shall be measured at least from 0° to 90° relative to the middle position of the UAS flight path. The UAS is flying without any fixed support.

7.3.4.2 UAS position and flight path

For the UAS in take-off and landing conditions, the flight path shall be vertical, and the flying speed during the acoustic measurement shall be constant. An example of the schematic for the UAS noise test is shown in Figure 5.



Key

1 UAS

H_0 minimum height of the UAS operation

L lateral distance of Mic 2

H_1 height of Mic 3
H_V distance of the UAS in vertical motion
H_m microphone clearance distance to walls and ground

NOTE The dashed arrow means that the UAS can fly in either take-off or landing state.

Figure 5 — Schematic of UAS noise test configuration in take-off and landing conditions

The UAS position and flight path are denoted as below.

a) The minimum height of the UAS operated at the nominal speed to Mic 1 is H_0 based on the requirement to reduce the aerodynamic impact is specified in 6.3.

- For the take-off cases, the initial location of the UAS operated at the nominal speed shall be at the height of H_0.
- For the landing case, the final location of the UAS operated at the nominal speed shall be at the height of H_0.

b) The distance H_V of the UAS flight is dependent on the flying speed and the measurement time interval T with the starting time t_1 and ending time t_2.

7.3.4.3 Microphone arrangement

The measurements use 3 microphones Mic 1, Mic 2, and Mic 3. The microphone distance to the anechoic chamber walls, ceiling and floor is denoted as H_m. The Locations of the microphones are denoted as below.

- Mic 1 is below the UAS, and it is used as the reference point.
- Mic 2 in the lateral direction is $L \geq 5D_A$ from Mic 1.
- Mic 3 in the lateral direction is L from the UAS, and the height is $H_1 = L$.

7.3.4.4 Measurement procedure

The measurements shall be conducted following the procedures.

a) The fully charged UAS shall hover at the initial location with the accuracy specified in 6.4.2.

b) The measurement starts at the same time when the UAS is in take-off/landing state. However, the recorded acoustic data for the UAS at the distance lower than H_0 shall not be used.

c) Conduct the measurement for at least 5 s, during which period the UAS is operated at the target flight speed with the accuracy required in 6.4.3.

d) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

e) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

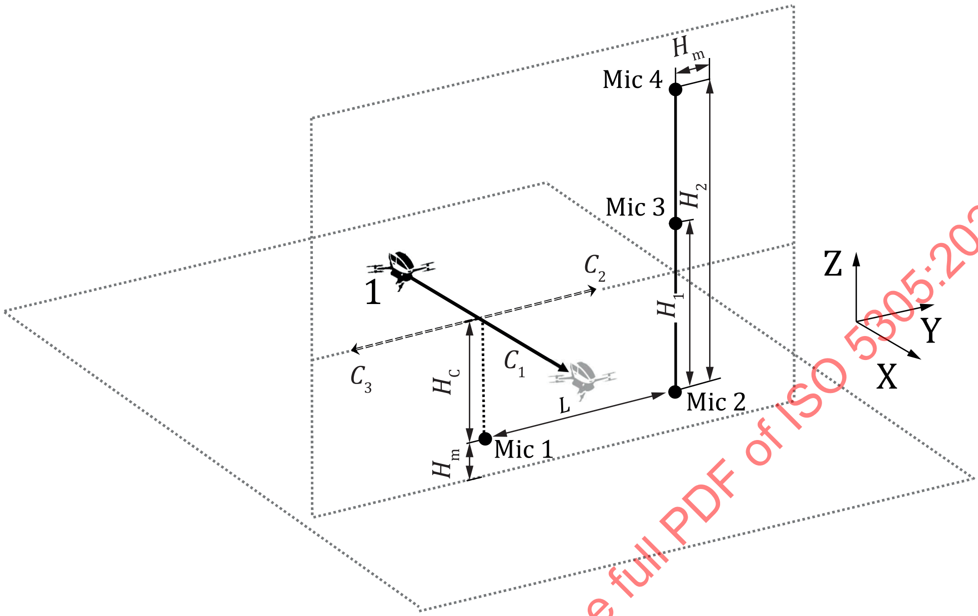
Usually, the measurement time of 20 s is recommended. However, if the UAS is in flight condition, the valid measurement time may be shortened due to the finite size of the anechoic chamber. Therefore, 5 s is the minimum requirement.

If the UAS flies at relatively high speed, the required size of the anechoic chamber can be too large to be fulfilled. In this case, alternative tests such as using anechoic wind tunnels or outdoor tests may be needed. The corresponding requirements are specified in Clauses 8 and 9 respectively.

7.3.5 Cruise flight

7.3.5.1 General

This subclause specifies the requirements of UAS noise measurement in cruise condition. The UAS is flying without any fixed support. A schematic of the noise measurement for the UAS in cruise condition is shown in Figure 6.



Key

1	UAS
H_m	microphone clearance distance to the ground or walls
H_C	height of the UAS in cruise
H_1	height of Mic 3
H_2	height of Mic 4
L	horizontal distance of between Mic 1 and Mic 2
C_1, C_2 and C_3	cruise paths of the UAS

Figure 6 — Schematic of the noise test configuration for UAS cruise tests

7.3.5.2 UAS position and flight path

a) For the UAS in cruise flights, the flight path is horizontal and the target flying speed is constant.

b) The height of the UAS is H_c. During the test, the configurations with $H_c = L$ shall be tested, where $L \geq 5D_A$ is the distance between Mic 1 and Mic 2, as shown in Figure 6.

c) 3 paths shall be tested:

- path C_1: the UAS flies directly over the ground microphone and travelling perpendicular to the plane containing all 4 microphones;
- path C_2: the UAS flies over the ground microphone and is within the plane containing all microphones. It is perpendicular to C_1 and the UAS flies away from Mics 2, 3 and 4;
- path C_3: the UAS flies over the ground microphone and is within the plane containing all 4 microphones and; it aligns with C_2, but in the opposite direction.

During cruise, the orientation of the UAS can differ from the flight direction. The UAS orientation should be kept unchanged in the repeated tests, and the orientation shall be documented and reported.

7.3.5.3 Microphone arrangement

a) 4 microphones are employed. The locations of the microphones are the same as the hover and yaw test cases shown in Figure 3.

b) The minimum distance of the UAS to Mic 3 in cruise paths C_2 and C_3 is larger than $2D_A$.

7.3.5.4 Measurement procedure

For each flight path, the measurements shall be conducted following the procedures.

a) The fully charged UAS shall hover at the initial height with the accuracy required in 6.4.2.

b) The measurement starts at the same time when the UAS is in cruise condition.

c) Conduct the measurement for at least 5 s, during which period the UAS is operated at the target speed with the accuracy required in 6.4.3.

d) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

e) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

NOTE An explanation of the minimum measurement time is given in 7.3.4.

If the UAS flies at relatively high speed, the required size of the anechoic chamber can be too large to be fulfilled. In this case, alternative tests such as using anechoic wind tunnels may be needed. The corresponding requirements are specified in Clause 8.

8 Anechoic wind tunnel tests

8.1 General

Tests using an anechoic wind tunnel can also provide a controllable condition for noise measurements of UAS in take-off, landing, and cruise flight states. Usually, the anechoic wind tunnel is enclosed by an anechoic chamber. The flight motion is replaced by the airflow from the wind tunnel such that higher speeds of interest can be tested than in anechoic chambers.

In wind tunnel tests, the UAS shall be mounted using fixed support located inside the test section. The support shall be designed with the fundamental frequency below the measurable blade passing frequency to minimize structural vibration. Streamlined fairing should be designed to reduce the effects on aerodynamic flows, and it shall be acoustically treated to minimize reflections. A load cell should be used to measure the thrust generated by the UAS. The flight system should be adapted such that the propeller rotation speeds are directly controlled to yield the target thrust.

8.2 Requirements of anechoic wind tunnel

8.2.1 General

Usually, the wind tunnel shall be enclosed by an anechoic chamber. The requirements of anechoic chamber qualification are the same as in 7.2.2.

8.2.2 Wind tunnel test configurations

a) The UAS should be mounted in the centre of the wind tunnel test section.

b) The maximum blockage ratio σ shall be in accordance with Formula (5)[13]:

$$\sigma = \frac{S_A}{S_W} \leq 0{,}1 \quad (5)$$

where

S_A is the frontal area of UAS in wind tunnel test;

S_W is the cross-section area of the wind tunnel; an illustration of S_W is given in Figure 7.

c) The UAS dimension shall be in accordance with Formula (6):

$$\frac{D_A}{D_W} \leq 0{,}6 \quad (6)$$

where

D_A is the UAS diameter defined in Figure 1;

D_W is the minimal diameter of the wind tunnel or the minimal length if the cross section is rectangular.

d) The flow across the UAS shall be uniform in the streamwise, vertical and transverse directions. The flow shall be uniform to 0,2 %.

e) The freestream turbulence intensity shall be less than 2 % at the location of the UAS.

f) The calibration of the wind speed shall be verified using a Pitot static tube at the location of the UAS before the tests.

g) An uncertainty analysis comprising of both type A and type B uncertainties for speed, atmosphere pressure, temperature, and the position shall be performed using ISO/IEC Guide 98-3.

8.2.3 Refraction correction

In open-jet wind tunnel experiments with non-zero wind speeds, the noise radiated from the UAS can be refracted by the shear layer of the wind tunnel. Therefore, a correction is needed for both the polar and azimuthal angles to account for its effect[14][15].

8.2.4 Microphone clearance distance

The microphones shall be placed in the qualified region of the anechoic chamber, as specified in 7.2.2**.** The distance of the microphone to the walls, floor or ceiling is denoted as H_m.

8.2.5 Anechoic chamber size

The anechoic chamber shall be sufficiently large to ensure the requirements of the distance between UAS and microphones to ensure far-field condition in 6.2, the distance between UAS and walls in 6.3, and microphone clearance distance H_m in 8.2.4.

8.3 Measurement configurations

8.3.1 General

In take-off, landing and cruise conditions, the UAS has a relative motion with the air, which can be realized by introducing airflow from the wind tunnel. In the tests of different working conditions, the attitude of the UAS mounted in the wind tunnel test section shall be adjusted accordingly.

Microphone arrays shall be used to measure the directivity of the UAS noise. An illustration of the observer angles θ and φ is shown in Figure 2.

— For take-off and landing conditions, the microphone array shall be horizontally placed. The observer angle θ shall be measured at least from 30° to 120° with a resolution of 15° or better. The directions shall be maintained with an accuracy of $\pm 1^\circ$.

— For cruise conditions, the microphone array shall be vertically placed. θ shall be measured at observer angles range from 45° to 135° with a resolution of 15° or better. The directions shall be maintained with an accuracy of $\pm 1^\circ$.

The directivity of the UAS noise at different observer angle φ shall be measured by adjusting the UAS orientation with an angle resolution of 30° or better.

In the wind tunnel test, the relatively distances of the UAS and the microphones are unchanged. Therefore, the measured sound pressures shall be scaled to the constant distance of $R_0 = 1$ m, as shown in Formula (4).

Before the measurements, the objective metric(s) to be computed from the measured sound pressure signals, as well as the confidence interval of the metric(s), should be given. Then, repeatability tests shall be conducted until the requirements are fulfilled.

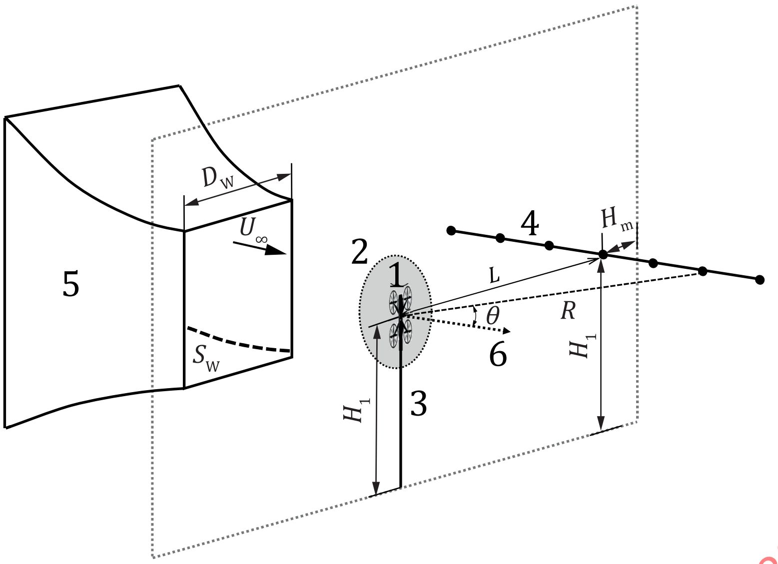
In wind tunnel tests, the A-weighted sound pressure level $L_{p,\mathrm{A}}$ should be employed as the noise metrics with a 95 % confidence interval of ± 1 dB. Here the confidence level refers to the random uncertainty during the repeatability tests.

NOTE For the repeated tests, this implies turning the tunnel and UAS motor off and then restarting them for the tests. It is not required to unmount and remount the UAS in the wind tunnel.

8.3.2 Take-off and landing

8.3.2.1 General

This subclause specifies the requirements of UAS noise measurement in take-off and landing conditions. A schematic of the test is shown in Figure 7. The minimum dimension of the wind tunnel test section is D_W and the area of the cross-section is S_W.



Key

1	UAS
2	plane of rotation
3	support
4	microphone array
5	wind tunnel
6	wind direction
H_1	height of the UAS centre to the ground; also the height of the microphone array to the ground
L	lateral distance of the microphone array
H_m	microphone clearance distance to the wall
D_w	minimal diameter of the wind tunnel or the minimal length if the cross section is rectangular
S_W	cross-section area of the wind tunnel
U_∞	wind speed
θ	observer angle
R	distance of the UAS centre to the microphone

The anechoic wind tunnel shall be enclosed by an anechoic chamber.

Figure 7 — Schematic of a UAS noise test in either take-off or landing states using an anechoic wind tunnel

8.3.2.2 UAS position

The UAS shall be mounted in the centre of the wind tunnel test section. The height of the UAS centre to the ground is denoted as H_1. The UAS attitude shall be adjusted such that the wind direction is perpendicular to the plane of rotation of the UAS rotors.

a) When the UAS is tested to mimic the take-off state, the UAS attitude shall be adjusted such that the oncoming wind impinges on the top side of the UAS plane of rotation.

b) When the UAS is tested to mimic the landing state, the UAS attitude shall be adjusted such that the oncoming wind impinges on the bottom side of the UAS plane of rotation.

8.3.2.3 Microphone array configuration

A microphone array is used in the horizontal direction to measure the UAS noise at observer angles ranging from 30° to 120° in increment of 15°. The angles shown here are geometric angle, and shear-layer correction[14][15] should be conducted if the wind tunnel is open test section, as specified in 8.2.3.

The microphone array has a height of H_1 to the ground. The lateral distance of the UAS centre is denoted as L, which shall be sufficiently large to ensure the corresponding microphone distance R of all microphones to the UAS centre satisfy the far-field condition specified in 6.2.

8.3.2.4 Measurement procedure

The measurements shall be conducted following the procedures.

a) Compute the required thrust to balance the UAS weight and drag.

b) Determine the rotational speeds of the propellers to provide the required thrust.

c) Start the measurement when the rotation speed reaches the target value.

d) Conduct the measurements for at least 20 s.

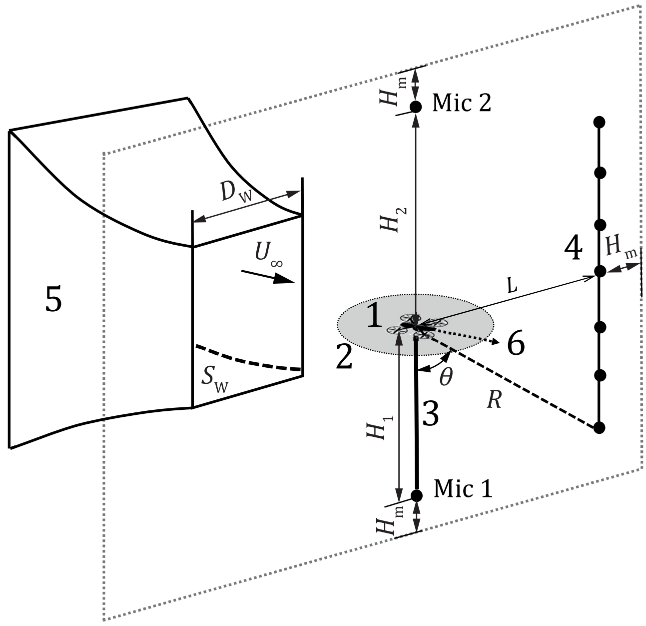
e) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

f) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

8.3.3 Cruise flight

8.3.3.1 General

This subclause specifies the requirements of UAS noise measurement in cruise conditions. A schematic of the test is shown in Figure 8.



Key

1	UAS
2	plane of rotation
3	support
4	microphone array
5	wind tunnel
6	wind direction
H_1	distance of the UAS centre to Mic 1
H_2	distance of the UAS centre to Mic 2
L	lateral distance of the microphone array
H_m	microphone clearance distance to the ground, ceiling and walls
D_W	minimal diameter of the wind tunnel or the minimal length if the cross section is rectangular
S_W	cross-section area of the wind tunnel
U_∞	wind speed
θ	observer angle
R	distance of the UAS centre to the microphone

The anechoic wind tunnel shall be enclosed by an anechoic chamber.

Figure 8 — Schematic UAS noise tests in cruise state using the anechoic wind tunnel

8.3.3.2 UAS position

The UAS shall be mounted in the centre of the wind tunnel test section. The height of the UAS centre to the ground is denoted as H_1.

In the wind tunnel tests, the UAS attitude shall be adjusted such that the angle between the oncoming wind and the UAS rotation plane equals the tilt angle of the UAS in cruise flight.

8.3.3.3 Microphone array configuration

A microphone array is used in the vertical direction to measure the UAS noise at observer angles ranging from 45° to 135° in an increment of 15°. The angles shown here are geometric angle, and shear-layer correction[14][15] should be conducted if the wind tunnel is open test section, as specified in 8.2.3.

The lateral distance of the microphone array to the UAS centre is denoted as L, which shall be sufficiently large to ensure the corresponding microphone distance R of all microphones to the UAS centre satisfy the far-field condition specified in 6.2.

Two microphones Mic 1 and Mic 2 located below and above the UAS are also employed to measure the UAS noise at vertical directions. The two microphones measure the sound pressure at $\theta = 0^\circ$ and 180°.

NOTE The use of vertical array can obtain the UAS noise in the lateral directions.

8.3.3.4 Measurement procedure

The measurements shall be conducted following the procedures.

a) Compute the thrust and attitude of the UAS to balance the UAS weight and drag.

b) Determine the propeller rotation speed to provide the required thrust.

c) Adjust the UAS attitude and mount the UAS in the test section.

d) Start the noise measurement when the rotation speed reaches the target value.

e) Conduct the measurement for at least 20 s.

f) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

g) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

9 Outdoor tests

9.1 General

Outdoor tests are needed for UAS noise measurements where the UAS is large and/or operates at high speed.

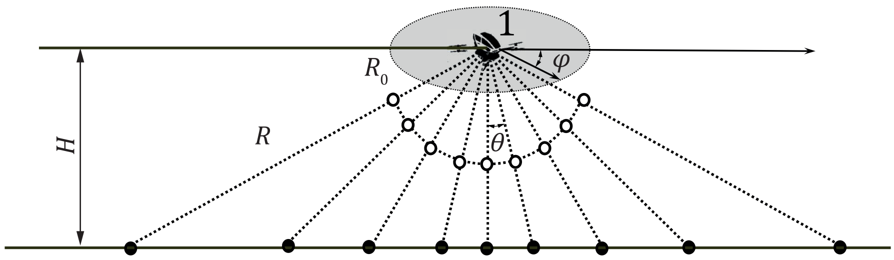
NOTE 1 Usually, the physical size of the UAS increases with the MTOM, making the acoustic far-field conditions hard to be satisfied in anechoic chambers. For example, for a UAS with an MTOM between 25 kg and 150 kg, it can be more suitable to conduct outdoor measurements.

NOTE 2 Even for UAS with small MTOM, if it is operated at relatively high speed, it is possible that the size of the anechoic chamber is not sufficient. For example, for the UAS at the cruises at a representative speed of 10 m/s, to test at least 5 s requires an anechoic chamber with a length of at least 50 m, which is challenging for practical applications. An approach is to use an anechoic wind tunnel and the requirements are specified in Clause 8. Another solution is based on the outdoor tests.

The outdoor test assumes an acoustic field in the half space above an infinite reflecting plane, in the absence of any other obstacles.

The outdoor test measures the time history of the sound pressure radiated from the UAS in the downward directions for θ ranges from -60° to 60° as shown in Figure 9. The measurements are performed with an angular resolution of 15° but may be increased for highly directional noise sources. The height H is the determined as the distance from the UAS centre to the ground.

NOTE 3 For the sound board tests, the increase of incidence angles of the normal to the ground can affect the accuracy. A study on the effect was conducted by Anderson *et al.*[16].



Key

1	UAS
H	height of the UAS
θ, φ	observer angles
R	distance of the UAS centre to the microphone on the ground
R_0	=1 m is the equivalent distance to scale the measured result

Figure 9 — Microphone positions relative to the UAS and recommended angular resolution for microphone placements

The directivity in the horizontal direction, defined by the angle φ shown in Figure 9, can be determined by changing the orientation of the UAS relative to the microphone positions with an angular resolution of 30° or smaller.

During outdoor testing, care shall be taken to minimize the effects of adverse meteorological conditions (e.g. low or high temperature, high humidity, wind, and precipitation) on the sound propagation and on sound generation over the frequency range of interest or on the background noise during the measurements.

The outdoor test method described here requires that microphones be mounted on ground-boards placed on the ground at the test area. The sound pressure measured by these microphones is corrected to an equivalent free-field sound pressure by dividing the measured sound pressure by two. This correction should be accurate provided the angle of incidence of the sound from the UAS to the microphone is within the limits prescribed in this document. Measurements made using incidence angles beyond this range may be subject to errors associated with diffraction from the edge of the ground-board and ground effects.

For hover and yaw measurements, the sound pressure measured on the ground are adjusted for the influence of the ground reflection. The sound pressure shall be scaled to the constant distance of $R_0 = 1$ m from the centre of the UAS, as shown in Figure 9.

Measurements made using microphones mounted above ground level (e.g. mounted on tripods or poles) are not recommended. This is because such measurements are likely to be affected by ground reflections due to interference between the direct incident sound from the UAS and the sound reflected from the ground plane. The exact interference effect can be constructive or destructive and depends on the frequency and incidence angle of the sound and the ground impedance. For a source with broadband noise characteristics, an overall sound pressure level measured over a wide frequency range may be calculated from above ground microphone measurements in accordance with ISO 1996-2[17]. However, this method may be not appropriate for multi-rotor UAS noise sources with significant tonal components.

9.2 Recommendations of the test site

The test site should be flat, horizontal, and large enough to ensure safe operation of the UAS. A suitable test site is a large open area where the ground is flat and horizontal and where there are no sound-reflecting objects in the near vicinity. The ground at the test site should be acoustically hard (being concrete, asphalt or similar), however, other ground types such as grass-covered soil are acceptable.

The ground type at the test area (e.g. grassland, concrete, hard soil) shall be reported.

There should not be reflecting objects in the near vicinity of the test area, the identification of which is defined below.

For this document, an object is considered as sound-reflecting if the following three conditions are fulfilled.

a) Its width exceeds one-tenth its distance to the nearest measurement position.

b) It is not covered with absorbing material, i.e., the cover should be acoustically hard and still to avoid sound absorption and resonance in the frequency range of interest.

c) There is an acoustical smooth surface capable of reflecting sound back in the direction of any of the measurement positions.

The distance between a reflecting object and the closest measurement position shall be at least twice the distance between any measurement position and the UAS position and shall not be smaller than 10 m. Contributions of reflections may be calculated in accordance with ISO 9613-2[18].

9.3 Recommendations and requirements of the meteorological conditions

a) The temperature, ambient pressure and relative humidity during the measurement period shall be measured at the test site at a height of between 1,2 m and 10 m above ground level. The time-average of these values during the measurement period shall be reported.

b) The wind speed and direction shall be measured at a location not more than 50 m from the microphone directly beneath the UAS (for hover, yaw, take-off and landing tests) or UAS flight path (for cruise tests) at a height of between 1,2 m and 10 m above the ground level. These measurements should be made at the nominal height of the centre of the UAS (for cruise, hover, and yaw tests) or the nominal height of the centre of the UAS at the mid-point of the flight path (for take-off and landing tests).

c) Measurements shall not be conducted during periods of precipitation (e.g. rain, hail, snow) at the height of the UAS.

Measurements should not be conducted if there is anomalous weather or wind conditions (e.g. gust, fierce wind and storm) at the test site that would significantly affect the UAS noise levels at the microphone locations.

9.4 Microphone configuration and layout

9.4.1 Microphone configuration

Measurements shall be made using a ground-board made from an acoustically reflecting material. The ground-board shall be circular with a diameter of at least 500 mm ± 2 mm and be between 2,5 mm and 10 mm thick. The sound pressure shall be measured at a radius 150 mm ± 2 mm from the centre of the ground-board with a pressure type microphone WS2P or WS3P as defined in IEC 61094-4. Examples of practical implementations of microphone configurations for ground boards are given in Annex F.

All microphones shall be fitted with an appropriate windscreen such that the A-weighted one-minute equivalent continuous sound pressure level of the wind sound at the wind speed of 10 m/s shall not exceed 65 dB.

The ground-board shall be placed horizontally and flush with the surrounding ground surface. To minimize heating by solar radiation, the upper surface of the ground-boards should be coloured white.

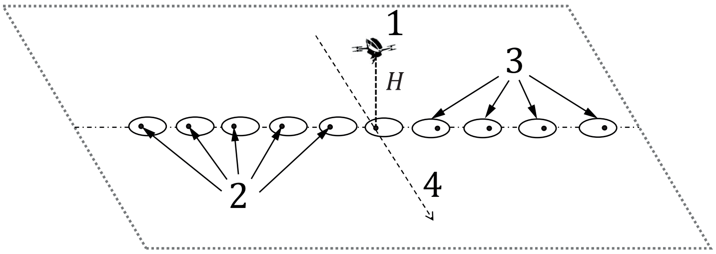
9.4.2 Microphone layout

The microphone positions on the ground shall be arranged in a straight line which is perpendicular to the UAS flight path (for cruise tests) and/or so that one microphone (the flyover microphone) is directly beneath the UAS (for hover, yaw, take-off, and landing tests) or UAS flight path (for cruise tests). The centre of the ground-boards should also lie on this line. Microphones should be placed symmetrically on either side of the flyover microphone. However, measurements may be made on only one side of the UAS if the noise source may be assumed to be symmetric.

The flight path shall be parallel to the wind direction to within $\pm 30^{\circ}$. The flight path direction shall be reported.

For the microphone not directly below the UAS or UAS flight path, the ground boards shall be oriented so that the microphone is located farthest from the UAS (for hover, yaw, take-off and landing tests) or the UAS flight path (for cruise tests).

A schematic of the microphone layout in the outdoor tests is shown in Figure 10.



Key

1 UAS

2 microphones

3 ground plates

4 flight path projection on the ground

Figure 10 — Schematic showing the microphone orientation and positions relative the UAS and flight path in the outdoor tests

The microphones shall be placed at locations every 15° measured from the vertical axis passing through the centre of the UAS when it is directly above the flyover microphone and, for the take-off and landing tests, at the middle of its flight path as shown in Figure 10. The height of the centre of the UAS above the ground during cruise, hover and yaw tests is nominally constant and is denoted as H. During take-off and landing tests, H is the height of the centre of the UAS at the mid-point of the flight path. A set-up using nine microphones is shown in Figure 10. For the case shown in Figure 10, the distance of the n^{th} microphone (where $n = 1,2,3,\cdots$) from the flyover microphone is equal to $H \times \tan\left(n \times 15^{\circ}\right)$.

No microphone should be placed a distance greater than $H \times \tan\left(60^{\circ}\right)$ from the flyover microphone. This is because the correction to account for the effect of the ground board may be inaccurate for measurements where the incident sound is obliquely incident on the microphone. Measurements made by microphones located at higher angles can therefore be inaccurate.

The distance between the UAS and the nearest microphone position shall be at least $5D_{\text{A}}$.

The height accuracy of the UAS shall be within $0,1H$ as specified in 6.4.2.

The lateral/horizontal location accuracy of the UAS shall be within $0,1H$ as specified in 6.4.2.

The microphone positions shall be within ± 50 mm of the nominal calculated positions.

NOTE This results in observer angles within $\pm 5^{\circ}$ of the nominal observer angles.

9.5 Measurement corrections and limitations

Only measurements taken during the period when the UAS was within a horizontal distance of $H \times \tan\left(60^{\circ}\right)$ from the flyover microphone should be used. This is to ensure the accuracy of the correction because of the ground board.

9.6 Measurement procedures

9.6.1 General

For the outdoor test, requirements and recommendations on the test site, corrections and microphone configurations are specified in 9.2, 9.3, 9.4 and 9.5. Procedures of the measurements under different UAS working conditions are specified in this subclause.

Measurements should be repeated enough times to quantify the repeatability of the measurement. Before the measurements, the objective metric(s) to be computed from the measured sound pressure signals, as well as the confidence interval of the metric (s), should be given. Then, repeatability tests shall be conducted until the requirements are fulfilled.

For the outdoor testing of UAS in hover and yaw conditions, the A-weighted sound pressure level $L_{p,\mathrm{A}}$ should be employed as the noise metrics with a 90 % confidence interval of ±1,5 dB, following ICAO Annex 16 Volume 1[19] for outdoor aircraft noise tests. Here the confidence level refers to the random uncertainty during the repeatability tests.

For the outdoor testing of UAS in take-off, landing and cruise flight conditions, either the maximum slow time-weighted A-weighted sound pressure level $L_{p,\mathrm{A,Smax}}$ or the A-weighted sound exposure level $L_{E,\mathrm{A},T}$ should be employed as the noise metrics with a 90 % confidence interval of ±1,5 dB, following ICAO Annex 16 Volume 1[19] for outdoor aircraft noise tests. Here the confidence level refers to the random uncertainty during the repeatability tests.

9.6.2 Hover and yaw

Measurements shall be conducted for the UAS at the height $H \geq 5D_\mathrm{A}$. Each measurement shall use the following procedure.

a) Operate the fully charged UAS at the nominal position ensuring that the UAS remains within the position accuracy limits specified in this subclause and in 6.4.2.

b) Conduct the measurement for at least 20 s.

c) Correct the sound pressure signals for the ground reflection.

d) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

d) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

In the measurements, the distance and observer angle of each microphone are different. Therefore, the sound pressure shall be scaled to the distance of $R_0 = 1$ m based on Formula (4).

9.6.3 Take-off and landing

Each measurement shall use the following procedure.

a) The fully charged UAS shall hover at the initial location with the accuracy specified in 6.4.2.

b) The measurement starts at the same time when the UAS is in take-off/landing state. The minimal distance of the UAS at the target flight speed shall be at least $H_0 = \max(2D_\mathrm{A}, H_\mathrm{s})$ and $H_\mathrm{s} = 1,2$ m. The measured acoustic data with the UAS height below H_0 shall not be used.

c) Conduct the measurement for the UAS flying to the end of the flight path, during which period the UAS is operated at the target flight speed with the accuracy requirement in 6.4.3.

d) Correct the sound pressure signals for the ground reflection.

e) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

f) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

9.6.4 Cruise flight

Each measurement should use the following procedure.

a) The fully charged UAS shall hover at the initial height with the accuracy required in 6.4.2.

b) The measurement starts at the same time when the UAS is cruise condition.

c) Conduct the measurement for the UAS flying to the end of the flight path, during which period the UAS is operated at the target flight speed with the accuracy requirement in 6.4.3. The recording period should include the period when the UAS is within a horizontal distance of $H \times \tan\left(60^{\circ}\right)$ from the flyover microphone.

d) Correct the sound pressure signals for the ground reflection.

e) Repeat the measurement until the target confidence interval of the objective metric(s) is realized.

f) The number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified, if applicable.

10 Uncertainties

10.1 General

The uncertainty quantifies the doubt about the measurement result. For each configuration, the number of measurements shall be reported in concurrence with the objective metric(s) to be captured and confidence interval of those metric(s) reported. The frequency range of the spectrum used to calculate the metrics shall be specified.

10.2 Uncertainty sources and requirements

For the UAS noise measurement, there are several sources of uncertainties. Some possible uncertainty sources and the corresponding requirements are listed as below:

a) the microphone, for example, drift and electrical noise; and the requirement is given by IEC 61672-1.

b) the microphone calibration; and the requirement is given by ISO 60942;

c) UAS position and motion error; and the requirements are given in 6.4;

d) the uncertainties due to the test environment of the anechoic chamber:

- the recirculation effect[20];
- anechoic chamber performance; and the requirement is given by ISO 26101-1;

e) the uncertainties due to the test environment of outdoor condition:

- the background noise; and the requirement is given in 6.5;
- the sound absorption and reflection by the ground;
- the meteorological conditions such as temperature, humidity, and air pressure;

— the wind speed and directions;

f) others.

10.3 Evaluation of the uncertainty

The measurement uncertainty should be reported in the results. For example, the A-weighted sound pressure level at a microphone in hover is written as

$$L_{p,\mathrm{A}} = \overline{L_{p,\mathrm{A}}} + \sigma_\mathrm{T} \quad (7)$$

where

$\overline{L_{p,\mathrm{A}}}$ can be computed following the procedures outlined in Annex A;

σ_T contains the uncertainty σ_R based on the repeatability tests and the possible contributions by multiple sources of uncertainties as listed in 10.2.

Each source corresponds to a specific value that quantifies the regarding effect on the measurement. An approach to quantify the overall uncertainty value is[21]:

$$\sigma_\mathrm{T} = \sqrt{\sigma_\mathrm{R}^2 + \sigma_\mathrm{M}^2 + \sigma_\mathrm{B}^2 + \sigma_\mathrm{C}^2 + \sigma_\mathrm{D}^2 + \sigma_\mathrm{P}^2 + \sigma_\Theta^2 + \sigma_\mathrm{U}^2 \cdots} \quad (8)$$

where

σ_R quantifies the uncertainty in the repeatability tests using T-distribution

σ_M quantifies the uncertainty due to the microphone

σ_B quantifies the uncertainty due to background noise

σ_C quantifies the uncertainty due to anechoic chamber measurement

σ_D quantifies the uncertainty due to position accuracy

σ_P quantifies the uncertainty due to ambient pressure

σ_Θ quantifies the uncertainty due to ambient temperature

σ_U quantifies the uncertainty due to wind speed

Therefore, the following steps are followed to evaluate the uncertainty.

a) Estimate all the uncertainties in similar terms.

EXAMPLE The effect of UAS position accuracy on the uncertainty can be estimated as

$$\sigma_\mathrm{D} = 20 \log_{10}(1 + \delta_\mathrm{R}) \approx 8{,}7\delta_\mathrm{D} \quad (9)$$

where $\delta_\mathrm{D} = |\Delta \boldsymbol{y}| / R$, and R is distance between microphone and UAS. $\Delta \boldsymbol{y}$ shows the position variation, and the requirement is given in 6.4.

b) Calculate the overall uncertainty.

c) Record the measurement results and their uncertainty.

In practice, if the data for uncertainty contribution is absent, values σ_R may be used as an estimate of the combined uncertainty.

NOTE An example to calculate the uncertainty of UAS noise measurement is given in Annex G.

11 Information to report

11.1 Test methods

The following information shall be reported:

a) the International Standard used (including its year of publication);

b) reference to the clauses of the standard to explain how the results are obtained;

c) any deviations from the procedures;

d) any unusual features observed.

11.2 Selected noise metrics

The noise metrics shall be selected before the test is performed. A detailed description of the metrics selected for the test shall be reported.

NOTE Recommendations of several commonly used noise metrics that can be employed for UAS noise measurements are provided in this document. Annex A gives examples of the computation procedures of those noise metrics.

11.3 UAS under test

The following information shall be reported:

a) a description of the UAS under test (including the manufacturer, type, configuration, blade number, MTOM, dimensions, serial number, technical data, and year of manufacture);

b) a description of flight attitudes (including speed, acceleration, duration, relative positions in the anechoic chamber or outdoors under take-off, yaw, hover, landing, and cruising if applicable).

11.4 Test environment

The following information shall be reported:

a) if it is in an anechoic chamber, the description of the anechoic chamber (including size, cut-off frequency) shall be reported;

b) if it is outdoors, the description shall include the nature of the ground surface and the surrounding terrain, with a sketch showing the location of UAS under test;

c) if it is in an anechoic chamber, the air temperature, in degrees Celsius, and the static pressure, in kilopascals, at the time of test shall be reported;

d) if it is in the outdoor test, a description of the meteorological conditions shall be reported, including wind speed, wind direction, atmospheric stability (e.g. cloud cover and time of day), temperature, barometric pressure, humidity, and locations of wind and temperature sensors;

e) background noise of the test environment.

11.5 Data acquisition system

The following information shall be reported:

a) a description of equipment for measurements (including the name, type, serial number, and manufacturer);

b) the date, place, and methods used to calibrate the sound calibrator and to verify the calibration of the instrumentation system;

c) the characteristics of the microphone windscreen, including the sound insulation loss, reducing effect of noise caused by wind.

11.6 Measurement

The following information shall be reported:

a) time, day, and place for measurements;

b) a thorough description of the measurement site;

c) the UAS orientation;

d) the relative distances between UAS and microphones;

e) the measurement time of each test;

f) time intervals between the repeatability measurements;

g) in wind tunnel tests, the wind speed and thrust of the UAS;

h) all measured sound pressures.

11.7 Results

This document specifies the requirements on measuring the sound pressure of the UAS. Once the data are collected, noise metrics selected before the test can be computed. The results for the selected noise metrics shall be reported.

No matter what noise metric is employed, the following information should be reported:

— the measured frequency range, frequency resolution and data processing method;

— the average value of the noise metric, and its deviation and uncertainties in the given confidence interval based on the repeatability tests;

— an analysis of the evaluated uncertainties following steps in 10.3.

Annex A
(Informative)

Examples of the procedures to compute noise metrics from the recorded sound pressure signals

A.1 General

This document aims at measuring the sound pressure signals $p(t)$ of the UAS operating at different microphones in different working conditions. The measurements can be conducted in anechoic chamber, anechoic wind tunnel or in outdoor environment; and the configurations and procedures are specified in Clauses 7, 8 and 9, respectively.

In cases when the relative distance of UAS and microphone is unchanged, sound pressure shall have been scaled to a constant distance of $R_0 = 1$ m as the acoustic far-field condition specified in 6.2 is satisfied.

In this annex, the procedures to compute the A-weighted sound pressure level $L_{p,\mathrm{A}}$, slow time-weighted A-weighted sound pressure level $L_{p,\mathrm{A,S}}$, maximum slow time-weighted A-weighted sound pressure level $L_{p,\mathrm{A,Smax}}$, and A-weighted sound exposure level $L_{E,\mathrm{A},T}$ are provided once the sound pressure signals $p(t)$ at a microphone are recorded.

— $L_{p,\mathrm{A}}$ is recommended in situations when the relative distance of UAS and microphone is unchanged, e.g. tests for hover and yaw conditions and in wind tunnels.

— $L_{E,\mathrm{A},T}$ is recommended in situations when the relative distance of UAS and microphone varies with time, e.g. tests for take-off, landing, and cruise conditions. It is recommended only in cases when the UAS noise is higher than the background noise by at least 6 dB during the period when the measured sound pressure is employed for computation.

— $L_{p,\mathrm{A,Smax}}$ is recommended for the outdoor testing where there are issues with using sound exposure level for small UAS.

To compute the noise metrics, the frequency range $f_\mathrm{L} \le f \le f_\mathrm{U}$, frequency resolution Δf, and window function in data processing shall be specified.

— A recommendation of the frequency resolution is $\Delta f \le 4{,}0$ Hz.

— A recommendation of the frequency range covers the one-third-octave bands with central frequencies from 100 Hz to 10 000 Hz should be in accordance with ISO 3744[4].

— A recommendation of the window function is Hanning window, following ISO/TS 20065[22].

NOTE The smallest frequency resolution Δf is limited by the measurement time T.

The upper frequency limit f_U should be lower than $f_\mathrm{s}/2$, where f_s is the sampling frequency of the microphone. The lower frequency limit f_L is limited by the test environment. In the anechoic chamber and anechoic wind tunnel, f_L shall be higher than the cut-off frequency of the anechoic chamber.

Before the measurement, the confidence interval (CI) of the selected noise metric(s) shall be specified, and repetitive measurements shall be conducted until the objective level is satisfied.

— For indoor testing in anechoic chamber or anechoic wind tunnel, a 95 % confidence interval of ±1,0 dB is recommended for the selected noise metric(s).

— For outdoor testing, a 90 % confidence interval of ±1,5 dB is recommended for the selected noise metric (s), e.g. $L_{E,\mathrm{A},T}$ or $L_{p,\mathrm{A,Smax}}$.

A.2 A-weighted sound pressure level

a) Compute the PSD of the measured sound pressure $p(t)$ over the stated time interval T,[23] based on which the narrow band spectrum can be obtained.

b) Apply A-weighting to the computed narrow band spectrum, as specified in IEC 61672-1.

c) Compute the square of the A-weighted sound pressure $p_\mathrm{A}^2(n)$ from the A-weighted spectrum in the frequency range $f_\mathrm{L} \le f \le f_\mathrm{U}$, where n is the index of repeatability test.

d) Denoting that N times of repeatability tests have been conducted, then perform arithmetic average of the square of A-weighted sound pressure

$$\overline{p_\mathrm{A}^2} = \frac{1}{N}\sum_{n=1}^{N} p_\mathrm{A}^2(n) \tag{A.1}$$

e) Compute the A-weighted sound pressure level

$$\overline{L_{p,\mathrm{A}}} = 10\log_{10}\left(\frac{\overline{p_\mathrm{A}^2}}{p_0^2}\right) \tag{A.2}$$

where $p_0 = 20\ \mu\mathrm{Pa}$ is the reference pressure.

f) Compute the CI and check if the objective confidence level is satisfied.

A.3 Slow time-weighted A-weighted sound pressure level

a) For each repeatability test with the index n, the starting time and ending time and denoted as $t_{1,n}$ and $t_{2,n}$. At a given time step $t \in (t_{1,n} + 1\ \mathrm{s}, t_{2,n} - 1\ \mathrm{s})$, compute the square of A-weighted sound pressure $p_\mathrm{A}^2(\xi,n)$ using the recorded sound pressure over the period $(\xi - 1\ \mathrm{s}, \xi + 1\ \mathrm{s})$.

b) Compute the slow time-weighted A-weighted sound pressure level

$$L_{p,\mathrm{A,S}}(t,n) = 10\log_{10}\left(\frac{\left(\frac{1}{\tau_\mathrm{s}}\right)\int_{t_0}^{t} p_\mathrm{A}^2(\xi,n)\, e^{-\frac{t-\xi}{\tau_\mathrm{s}}}\,\mathrm{d}\xi}{p_0^2}\right) \tag{A.3}$$

where $p_0 = 20\ \mu\mathrm{Pa}$ is the reference pressure and $\tau_s = 1$ s.

A.4 Maximum slow time-weighted A-weighted sound pressure level

a) For each repeatability test with the index n, compute the slow time-weighted A-weighted sound pressure level $L_{p,\mathrm{A,S}}(t,n)$ following Formula (A.3).

b) Determine the maximum value $L_{p,\mathrm{A,Smax}}(n)$ during the stated time interval.

c) Denoting that N times of repeatability tests have been conducted, then perform arithmetic average of the maximum time-weighted A-weighted sound pressure level

$$\overline{L_{p,\mathrm{A,Smax}}} = \frac{1}{N}\sum_{n=1}^{N} L_{p,\mathrm{A,Smax}}(n) \tag{A.4}$$

d) Compute the CI and check if the objective confidence level is satisfied.

NOTE $L_{p,\text{A},\text{Smax}}$ coincides with the definition of maximum time-weighted sound level in IEC 61672.

A.5 A-weighted sound exposure level

a) For each repeatability test with the index n, the starting time and ending time and denoted as $t_{1,n}$ and $t_{2,n}$. The starting and ending times shall be determined when the time-averaged sound pressure level over 1 second is lower than the peak value by 10 dB. The individual starting and ending times $t_{1,n}$ and $t_{2,n}$ should be recorded and reported.

b) At a given time step $t \in (t_{1,n} + 1\,\text{s}, t_{2,n} - 1\,\text{s})$, compute the square of A-weighted sound pressure $p_\text{A}^2(t,n)$ using the recorded sound pressure over the period $(t - 1\,\text{s}, t + 1\,\text{s})$.

c) Compute the A-weighted sound exposure $E_{\text{A},T}(n)$ over the stated time interval T (starting at $t_{1,n}$ and ending at $t_{2,n}$):

$$E_{\text{A},T}(n) = \int_{t_{1,n}}^{t_{2,n}} p_\text{A}^2(t,n)\,\text{d}t \quad \text{(A.5)}$$

d) Denoting that N times of repeatability tests have been conducted, then perform arithmetic average of the sound exposure:

$$\overline{E_{\text{A},T}} = \frac{1}{N} \sum_{n=1}^{N} E_{\text{A},T}(n) \quad \text{(A.6)}$$

e) Compute the sound exposure level $\overline{L_{E,\text{A},T}}$ as:

$$\overline{L_{E,\text{A},T}} = 10 \log_{10} \left(\frac{\overline{E_{\text{A},T}}}{E_0} \right) \quad \text{(A.7)}$$

where $E_0 = 4 \times 10^{-10}\ \text{Pa} \cdot \text{s}$.

f) Compute the CI and check if the objective confidence level is satisfied.

Annex B
(Informative)

Numerical examination of the acoustic far-field condition

B.1 General

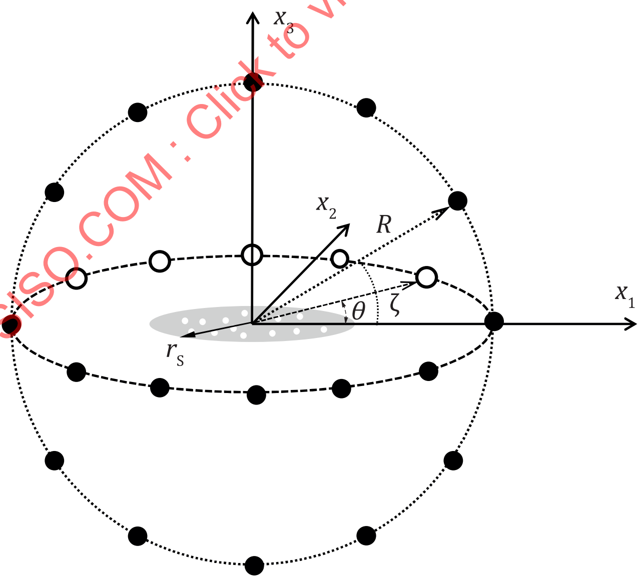
This annex introduces numerical experiments are conducted to demonstrate the validity of the far-field condition.

B.2 Case configuration

Multiple point sources are placed in the possible source region with a radius of r_s, which can be viewed as $0{,}5D_A$ of the vehicle diameter. The location $\boldsymbol{y}_n$ and amplitude A_n of these point sources are randomly configurated. Then the sound at a microphone with the coordinate $\boldsymbol{x}_o = (x_1, x_2, x_3)$ is computed as

$$p(\boldsymbol{x}_o) = \sum_{n=1}^{N} \frac{A_n e^{-ikr_n}}{4\pi r_n} \quad \text{(B.1)}$$

where $r_n = |\boldsymbol{x}_o - \boldsymbol{y}_n|$. Also $k = 2\pi f / c_0$ is the acoustic wave number, N is the number of point sources. To study the directivity patterns, microphones are placed at two circles with the radius R. One circle is parallel to the source region and the other one is perpendicular to the plane. A schematic of the microphones is shown in Figure B.1.



Key

r_s radius of the source region

θ, ζ observer angles

R distance of the UAS centre to the microphone

Figure B.1 — Schematic of the distribution noise sources (dots in the grey region) and microphone locations (dashed circles)

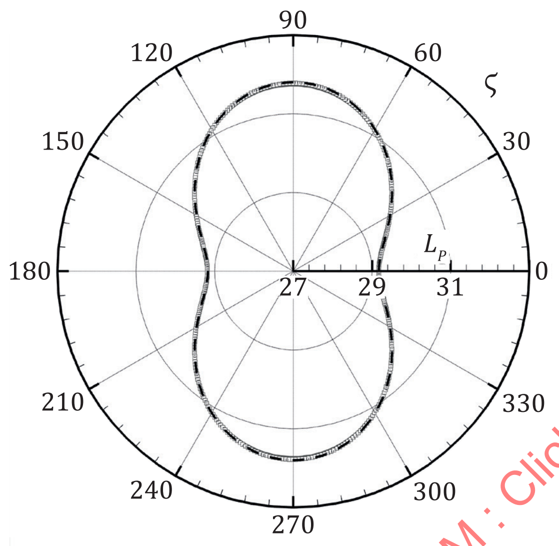
To examine if the far-field condition is satisfied, a normalized sound pressure level is defined:

$$L_P(\theta) = 20\log_{10}\left(\left|p(\theta)\right|R\right) \tag{B.2}$$

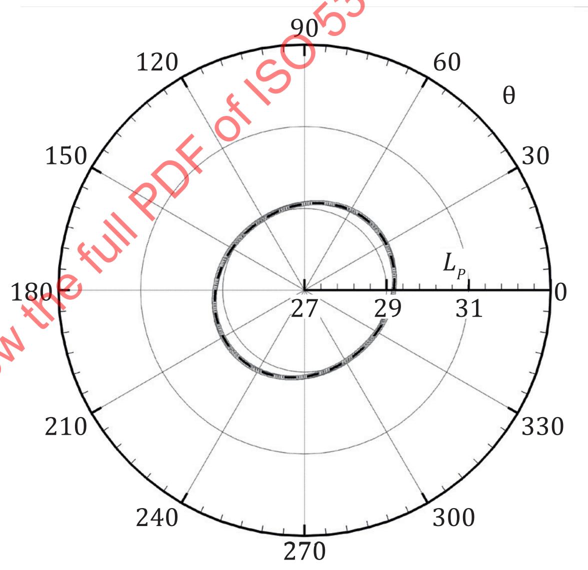
If the far-field condition is satisfied, L_P tends to be independent of the radius.

B.3 Examples

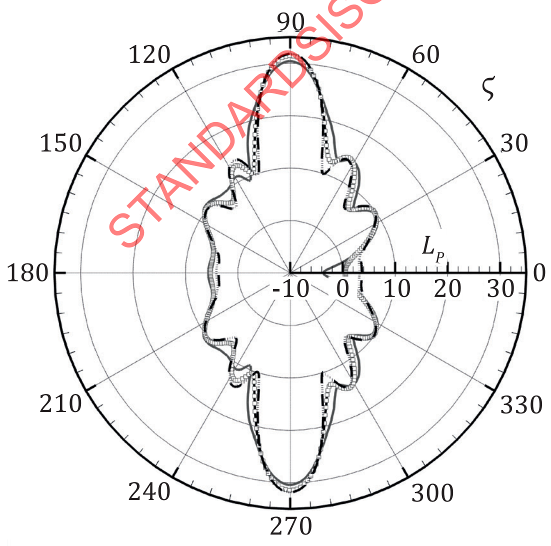
The normalized sound pressure level L_P is studies at different frequencies of 100 Hz, 1 000 Hz and 5 000 Hz. In the numerical test, $r_s = 1$ m and $N = 1\,000$ are set to model the sources. The radius R ranges from $5r_s$ to $50r_s$. The results at a sufficiently large distance of $R = 1\,000\,r_s$ are also computed for reference. The results of the two circles are shown in Figure B.2. At 100 Hz, it can be seen that the normalized values are close to the results with $R = 1\,000\,r_s$ even for the case of $R = 5r_s$. With the increase of sound frequency, a larger distance is needed to yield the far-field condition because the short wavelength can cause more spatial variations. However, at 1 000 Hz, the normalized results are close to a constant curve when $R = 10r_s$.



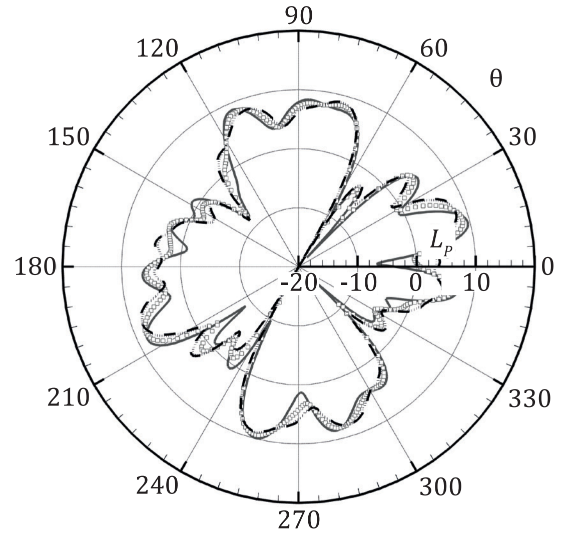
a) $x_1 - x_3$ plane, 100 Hz



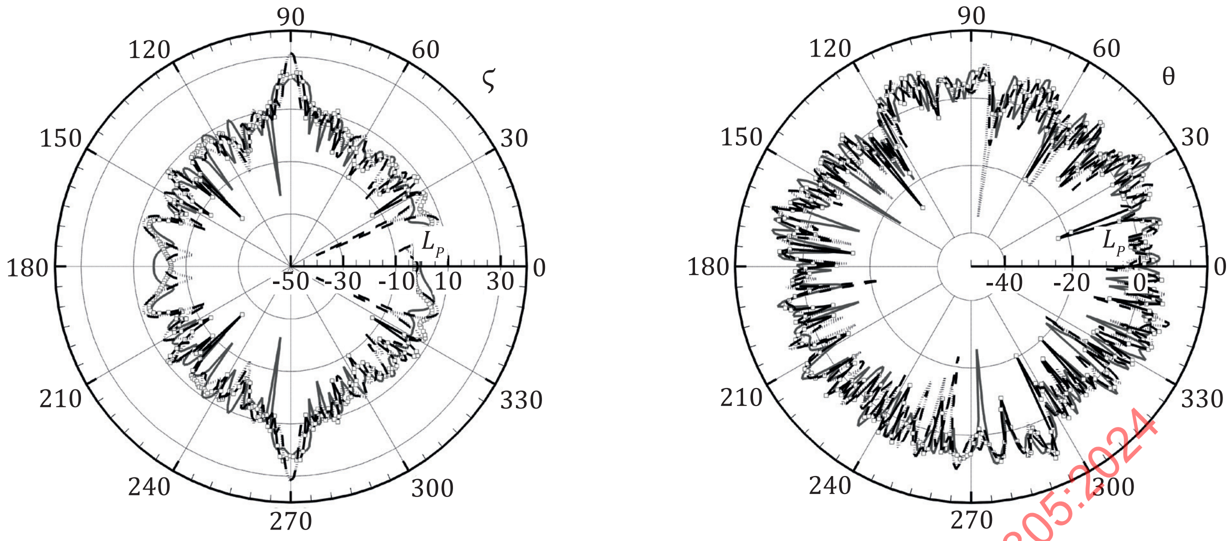
b) $x_1 - x_2$ plane, 100 Hz



c) $x_1 - x_3$ plane, 1 000 Hz



d) $x_1 - x_2$ plane, 1 000 Hz



e) $x_1 - x_3$ plane, 5 000 Hz

f) $x_1 - x_2$ plane, 5 000 Hz

Key

L_P normalized sound pressure level

r_s radius of the source region

θ, ζ observer angles

R distance of the UAS centre to the microphone

——— $R = 5r_s$

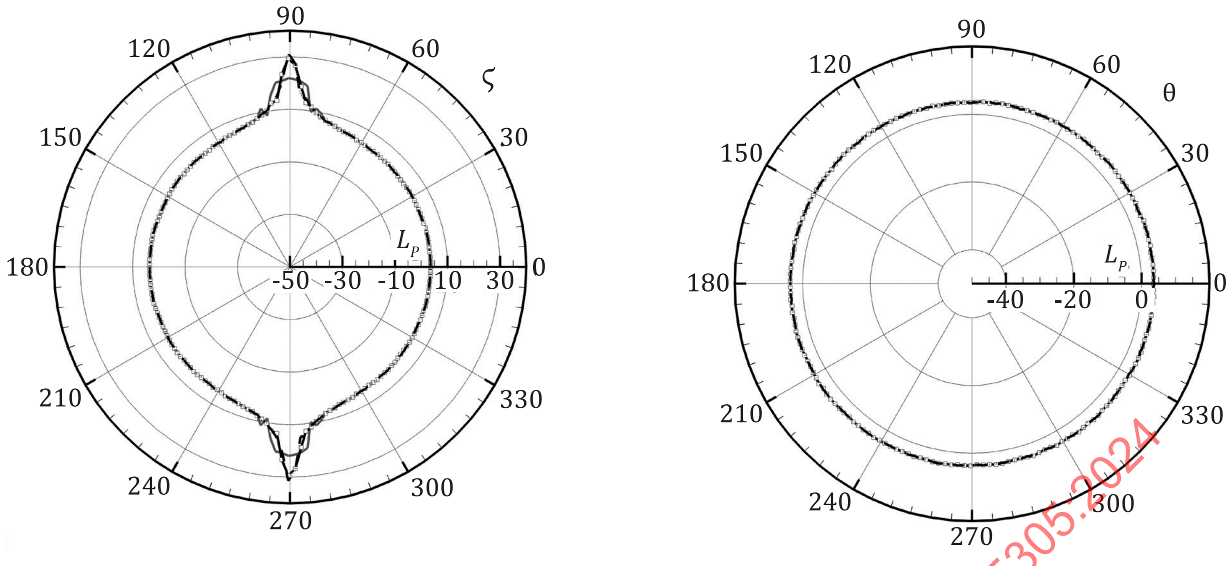
—□— $R = 10r_s$

.... $R = 50r_s$

- - - - $R = 1\ 000r_s$

Figure B.2 — Normalized sound pressure levels of distributed point sources

At the frequency of 5 000 Hz, more peaks and dips are found in the normalized directivities. The rapid variation of sound pressure level with observer angle makes it difficult to determine the exact directivity pattern. In practical application, the noise at high frequency is often due to the broadband contents. In this case, the noise is often characterized in a frequency range with a finite bandwidth. In this case, an average is performed, and the fluctuations with observer angles can be removed. For example, the computation is conducted in the 1/3-octave band at the central frequency of 5 000 Hz. The results are shown in Figure B.3. It can be seen the fluctuations are well suppressed, and the results tend to the constant curves if $R \geq 10r_s$.



a) $x_1 - x_3$ plane, 5 000 Hz

b) $x_1 - x_2$ plane, 5 000 Hz

Key

L_P	normalized sound pressure level
r_s	radius of the source region
θ, ζ	observer angles
R	distance of the UAS centre to the microphone
———	$R = 5r_s$
—□—	$R = 10r_s$
········	$R = 50r_s$
- - - - -	$R = 1\,000r_s$

Figure B.3 — Normalized sound pressure levels of distributed point sources in 1/3-octave band

B.4 Summary

The examples shown in this annex is based on the simplified modelling of point sources in a finite source region. The examples show that the far-field condition can be achieved if $R \geq 10r_s$. The higher frequency contents can cause significant interference patterns, causing more considerable distances to meet the requirement of the far-field condition. However, the high-frequency components are often due to broadband noise. The fluctuations with observer angles can be removed when performing average in a frequency band. In this case, the condition of $R \geq 10r_s$ was tested to be sufficient.

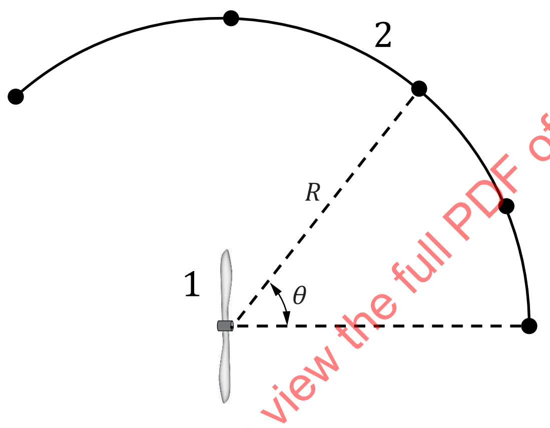
NOTE In practice, the UAS noise source can have different properties with the simplified modelling of the distributed source. However, test results using a propeller in the anechoic chamber in this annex suggest $R \geq 10r_s$ can be valid.

Annex C
(Informative)

Measurement of far-field condition for a UAS propeller noise

This annex presents the measurement of the UAS propeller noise at different observer distances to check the validity of the far-field condition.

A representative propeller, with a diameter (D_R) of 0,24 m has been employed for the acoustic far-field qualification. In this test, five free-field microphones are placed on traverses in five different directions, respectively. The acoustic measurement was taken place in the UNITED facility at the Hong Kong University of Science and Technology (HKUST). The measurements of the far-field condition in an anechoic chamber followed the requirements by ISO 26101-1.



Key

1 UAS propeller

2 arc support

θ observer angle

R distance of the UAS centre to the microphone

Figure C.1 — Schematic of the far-filed qualification of an UAS propeller in the anechoic chamber at HKUST

Figure C.1 shows the experimental schematic for the far-field qualification of a UAS propeller. The traverse used to qualify the free-field condition is along 5 radial traverse paths and 10 points are taken per traverse. The tonal noise at the blade passing frequency (BPF) was investigated to characterise the noise frequency (and wavelength). For the propeller working at 7 800 RPM, the frequency at the BPF of 260 Hz is studied. The minimal microphone distance r on each traverse is 0,4 m, which is larger than a quarter of a wavelength at this frequency.

To quantify the far-field condition, the dependence of the measured sound pressure levels with the microphone distance r is studied, and the results are compared with the required maximum allowable deviation specified by ISO 26101-1, i.e. at the frequency lower than 630 Hz, the maximum allowable deviation is ±1,5 dB; in the range of 800 Hz to 5 000 Hz, the maximum allowable deviation is ±1,0 dB and for frequency higher than 6 300 Hz, the allowable deviation is ±1,5 dB.

Figure C.2 shows the results the propeller operated 7 800 RPM, and the corresponding tonal noise at the BPF is 260 Hz. The tonal noise results at the BPF and the 1/3-octave band results at 1 000 Hz are presented. The results suggested the far-field condition is satisfied when the microphone distance is larger than 1,2 m, which is $5D_A$ as specified in 6.2. based on the analysis in Annex B.