European Union Aviation Safety Agency

Guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk)

Public Consultation

EXECUTIVE SUMMARY

This is a consultation on Guidelines published by EASA for the measurement of the noise of Unmanned Aircraft (UA) with an MTOM lower than 600 kg. These guidelines are offered to be used for measuring the noise of UA operated in the specific category. Manufacturers or operators may voluntary measure noise according to these guidelines and provide the data to EASA.

Stakeholders are invited to comment on these Guidelines in order to ensure they are fit for purpose.

Released on 13 October 2022.

Public consultation on the EASA Comment-Response Tool (CRT) at http://hub.easa.europa.eu/crt/. Deadline for submitting comments: 13 January 2023 (23:59)

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INTRODUCTORY NOTE

In 2018, a new Basic Regulation (Regulation (EU) 2018/1139) was adopted, followed by the new European Commission Implementing Regulation (EU) 2019/947 (which became applicable on 31 December 2020) and Delegated Regulation (EU) 2019/945 (which became applicable on 1 July 2019). These documents set the new UAS regulatory framework, which is a proportional risk-based approach to UAS. Its pillar is the identification of three categories of operation: 'open', 'specific' and 'certified'.

Regulation (EU) 2019/945 includes noise requirements through the CE marking for a limited number of UAS operations (for the 'open' category and for the 'specific' category for operations complying with a standard scenario).

For operations in the 'specific' category, an operational authorization issued by the competent authority of registration is required, unless the operation is covered by a standard scenario. These guidelines can be used, where deemed appropriate by the competent authorities, to assess noise emissions when issuing the operational authorization for UAS operating in the 'specific' category (low and medium risk). They provide a consistent method for measuring the noise of Unmanned Aircraft (UA) with an MTOM lower than 600 kg. This method can be applied on various UA designs (multicopters, fixed-wing aircraft, helicopters, powered-lift aircraft and more) and caters for two procedures: a level-flight, and for the UA designs that allow stationary flight, a hover flight.

The proposed method is the outcome of several years of UA noise studies conducted by the Agency, with consideration for practical aspects as well as human perception of UA noise (psychoacoustics).

The noise measurement method is designed to provide repeatable and accurate noise measurements and noise levels allowing for fair comparison between various UA designs. They are intended to be relevant to the regular envisioned UA operations, while remaining proportionate (in complexity and cost) to the design of UA's.

These guidelines can be used for instance by UAS manufacturers, operators or noise measurement organisations, on a voluntary basis, to establish noise levels associated to particular designs and operations. It is recommended that the resulting noise levels be reported to the Agency, who later intends to build an online public repository available to the operator for the statement of compliance of the UAS with the Union and national rules related to environmental protection and to the competent authority in order to assess this statement.

SUBPART A – GENERAL

Noise.UAS.110 Definitions

IM: Interpretative Material.

MoC: Means of Compliance.

Noise measurement point: the point where the microphone is located.

Test (or Noise Test): designates the collection of all field measurements carried out to obtain the sound levels of the UA. A test comprises of several test runs.

Test run: designates only one occurrence of a test procedure, for instance one UA passage over the noise measurement point.

UA: Unmanned Aircraft.

SUBPART B – NOISE EVALUATION METRICS

Noise.UAS.210 Applicable noise evaluation metrics

(a) For the reference level-flight procedure defined in Noise.UAS.320, the noise evaluation metric must be the A-weighted sound exposure level (L_{AE}) measured in dB(A), as defined in Noise.UAS.220.

(b) For the reference hover procedure defined in Noise.UAS.320, the noise evaluation metric must be the A-weighted equivalent continuous sound pressure Level (L_{Aeq}) measured in dB(A), as defined in Noise.UAS.220.

Noise.UAS.220 Noise evaluation metrics definitions

(a) A-weighted sound exposure level

The A-weighted sound exposure level, L_{AE}, is defined as the level, in units of dB(A), of the time integral of squared A-weighted sound pressure, p_A, over a given time period or event, with reference to the square of the standard reference sound pressure, p_0, of 20 µPa and a reference duration of one second.

This metric is defined by the expression:

$$L_{AE} = 10 log \frac{1}{t_0} \int_{t_1}^{t_2} \left(\frac{p_A(t)}{p_0} \right)^2 dt$$

where t_0 is the reference integration time of one second and (t_2 – t_1) is the integration time interval.

The above integral is approximated from periodically sampled measurement as:

$$L_{AE} = 10 log \frac{1}{t_0} \sum_{k_F}^{k_L} 10^{0.1 L_{AS}(k)} \Delta t$$

Where:

$L_{AS}(k)$ is the time varying A-frequency-weighted SLOW-time-weighted[1] sound level in units of dB(A) measured at the k^{th} instant of time (A-frequency weighting is defined in (c)),

k_F and k_L are the first and last increment of k, and

Δt is the time increment between samples.

The integration time (t_2 – t_1) must not be less than the true 10 dB(A)-down period during which $L_{AS}(t)$ first rises to 10 dB(A) below its maximum value L_{ASmax} and last falls below 10 dB(A) of its maximum value L_{ASmax}.

(b) A-weighted equivalent continuous sound pressure level

The A-weighted equivalent continuous sound pressure level, L_{Aeq}, is defined as the level, in dB(A), of the time integral of squared A-weighted sound pressure, p_A, over a given time period, with reference to the square of the standard reference sound pressure, p_0, of 20 µPa and a reference duration of one second.

[1] SLOW time weighting (also designated as "S") is defined as an exponential time weighting with rise and decay times of 1 second.

This metric is defined by the expression:

$$L_{Aeq} = 10log\frac{1}{T_M}\int_0^{T_M}\left(\frac{p_A(t)}{p_0}\right)^2 dt$$

where T_M is the time interval corresponding to the measurement, with a value of 30 seconds.

The above integral is approximated from periodically sampled measurement as:

$$L_{Aeq} = 10log\frac{1}{T_M}\sum_{k=1}^{N}10^{0.1L_{AS}(k)}\Delta t$$

Where:

$L_{AS}(k)$ is the time varying A-frequency-weighted SLOW-time-weighted sound level in dB(A) measured at the k^{th} instant of time (A-frequency weighting is defined in (c)),

N is the last increment of k corresponding to the duration of TM=30 seconds, and

Δt is the time increment between samples.

IM1 Noise.UAS.220 Noise evaluation metrics definitions

A-FREQUENCY WEIGHTING AND SLOW-TIME WEIGHTING

The A-frequency weighting correction curve is defined in the IEC 61672-1 (“Electroacoustics — Sound level meters — Part I: Specifications”, 2013), and is a standard feature in sound level meters and other sound analysis equipment. The SLOW-time weighting is also defined in the same document (referred to as “time-weighting S”.

SUBPART C – REFERENCE CONDITIONS AND PROCEDURES

Noise.UAS.310 Reference noise measurement points

For the reference level-flight procedure, the reference noise measurement point is located on the ground, 50 m vertically below the UA, when the UA flies the reference level-flight procedure defined in Noise.UAS.320(b).

For the reference hover procedure, the reference noise measurement point is located on the ground, 25 m vertically below the UA, when the UA flies the reference hover procedure defined in Noise.UAS.320(c).

Noise.UAS.320 Reference procedures

(a) The noise levels must be determined under the reference atmospheric conditions defined in Noise.UAS.330 for the reference procedure defined in (b). Additionally, if the design of the UA permits stationary flight, the noise levels must be determined according to the reference procedure defined in (c).

(b) The reference level-flight procedure is defined as follows:

(1) the UA flies in a stabilized level flight condition at the vertical above the reference noise measurement point at a height of 50 m, where the height is considered between the ground and the centre of gravity of the UA;

(2) the reference ground speed V_{Gref} is:

(i) the fastest speed at which the level flight can be safely maintained under the reference atmospheric conditions;

(ii) maintained throughout the flight;

(3) the reference level-flight profile is defined for a flat terrain throughout the entire flight path;

(4) the mass of the UA is the maximum take-off mass (MTOM);

(5) The UA must be in the configuration for level-flight.

(c) The reference hover procedure is defined as follows:

(1) the UA is stabilized in a stationary flight directly above the reference noise measurement point at the reference height of 25 m, where the height is considered between the ground and the centre of gravity of the UA;

(2) the mass of the UA is the MTOM.

Noise.UAS.330 Reference atmospheric conditions

The reference atmospheric conditions for the reference procedures defined in Noise.UAS.320 are defined as follows:

(a) sea level atmospheric pressure of 101325 Pa;

(b) ambient air temperature of 25°C;

(c) relative humidity of 70 per cent;

(d) zero wind.

SUBPART D – NOISE LIMITS (*RESERVED)*

SUBPART E – NOISE TEST

Noise.UAS.510 Scope

The noise test must be conducted under the conditions and procedures specified under this subpart to yield valid measured sound levels L_{AE} and L_{Aeq}.

Noise.UAS.520 Test environment conditions

(a) The noise measurement point must be located on a relatively flat terrain, which has no excessive sound absorption characteristics.

(b) The conical space above the noise measurement point defined by an axis normal to the ground and by a half-angle of 75° from this axis must be free of obstructions that could influence the propagation of noise between UA and microphone.

(c) The test must be carried out under the following atmospheric conditions:

(1) there must be no precipitation;

(2) the temperature and the relative humidity must be restricted as follows:

(i) the temperature must be greater than or equal to 5°C and lower than or equal to 35°C;

(ii) the relative humidity must be greater than or equal to 20% and lower than or equal to 90%;

(iii) the combined values of the temperature and the relative humidity must be within the allowable test conditions depicted in Figure1 Noise.UAS.520 below. For values of relative humidity between 20% and 56% inclusive, the temperature must be greater than or equal to the value defined by the following equation, where RH is the relative humidity in % and T the temperature in °C:

$T = -2.43 \times 10^{-4} \times RH^3 + 3.6 \times 10^{-2} \times RH^2 - 2.3 \times RH + 63.58$

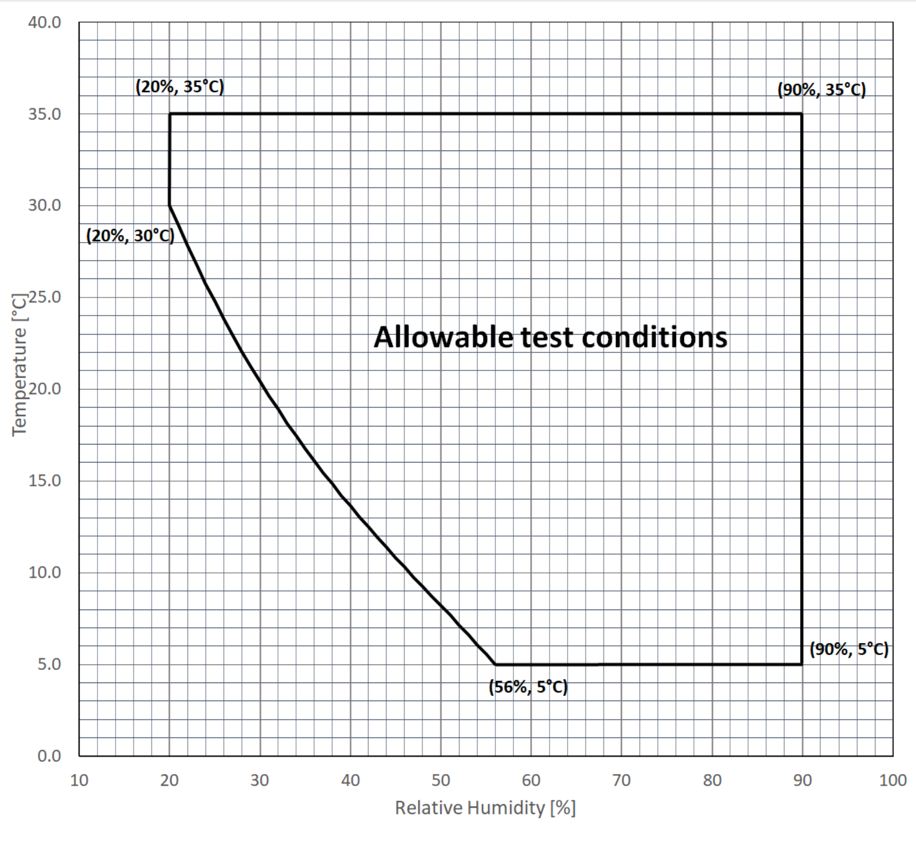

Figure 1: Allowable test conditions

(3) the wind speed must be averaged on 30 seconds and must be restricted as follows:

(i) for the level-flight procedure, the average wind speed must be lower than or equal to 4.1 m/s and the average crosswind component must be lower than or equal to 2.1 m/s. If the wind speed measurement device does not provide enough information to compute the crosswind component, then the wind from any direction must be lower of equal to 2.1 m/s.

(ii) for the hover procedure, the average wind speed must be lower than or equal to 2.1 m/s.

(d) The temperature, the relative humidity, the wind speed and direction and the atmospheric pressure must be measured for each run:

(1) at a height between 1.2 m and 10 m above the ground level;

(2) in the vicinity of the noise measurement point.

(e) The meteorological instruments must be operated within their environmental limitations as specified by their manufacturer. The accuracy of the temperature and the relative humidity sensors must be equal to or better than the following values:

(1) ±0.5°C for the temperature;

(2) ±3% for the relative humidity or ±0.5°C for both the dry bulb and the dew point temperatures when the relative humidity is measured with a psychrometer.

MoC1 Noise.UAS.520 Test environment conditions

METEOROLOGICAL INSTRUMENTS

(a) An airport meteorological station, or any official national weather forecast station can be used, if it is located within 2 000 m of the noise measurement point, if the equipment complies with the specifications, and if it is located in weather conditions representative of the conditions existing over the geographical area in which noise measurements are made.

(b) The temperature can be measured with a temperature sensor that meets the tolerance Class B requirements of IEC 60751 ("Industrial platinum resistance thermometers and platinum temperature sensors", 2nd edition, July 2008). The accuracy of such a sensor is equal to or better than ±0.5°C.

IM1 Noise.UAS.520 Test environment conditions

NOISE MEASUREMENT CONDITIONS

Thick, matted, tall grass, shrubs, or wooded areas are terrains that absorb sound excessively. In addition, people who carry out the measurements may constitute an obstruction that significantly influences the sound measurement.

Noise.UAS.530 Flight test procedures

(a) The UA used for the test must conform to its production design.

(b) The UA must be set to its MTOM for the entire duration of the test.

If the UA design leads to a mass decrease as the test progresses, any test run where the mass of the UA is lower than 90 percent of its MTOM must be rejected.

If the UA must be loaded with additional external elements to achieve the specified mass, care must be taken that such elements do not shield the sound propagation from the noise sources to the noise measurement point. Moreover, if such additional elements prevent a proper determination of the UA height when using the photographic scaling method of MoC2 Noise.UAS.550(b), the positioning and speed of the UA must then be determined by the augmented GNSS method of MoC2 Noise.UAS.550(a).

(c) For the level-flight procedure:
  (1) a minimum of six runs must be performed, and the number of flights made with a headwind component must be equal to the number of flights made with a tailwind component;
  (2) the UA must be stabilized in level flight over a distance sufficient to ensure that the time-varying A-frequency-weighted SLOW-time-weighted sound level is measured over the entire time period during which the sound level is within 10 dB(A) of L_{ASmax};
  (3) the ground speed of the test vehicle must be maintained constant throughout the test run;
  (4) the UA must be flown at a height between 17 m and 150 m above the noise measurement point;
  (5) the UA must be flown such as to not exceed a lateral deviation of ±10° from the vertical above the noise measurement point;
  (6) if the UA design permits multiple configurations in terms of control input and surfaces, the noisiest configuration must be selected and maintained throughout the entire flight. If the configuration producing the highest noise cannot easily be identified, all possible configurations must be tested and the noisiest one retained for reporting;

(d) For the hover procedure:
  (1) a minimum of six runs must be performed;
  (2) the UA must be set to maintain a stabilized hovering position during 30 seconds at the vertical above the noise measurement point;
  (3) the LAeq must result from the A-weighted SLOW-time-weighted sound level averaged over 30 seconds;
  (4) the test height to be considered for a run must be the arithmetic average of the measured height over the time range of the noise acquisition.
  (5) the UA height above the noise measurement point, averaged over the 30 seconds of noise recording, must be between 12 m and 50 m.
  (6) the UA must remain within a 6° cone from the vertical above the noise measurement point during the 30 seconds of noise recording;
  (7) the UA vertical deviation must be within 1 m from the measured height averaged over the 30 seconds of noise recording;
  (8) the UA must be flown outside of the conditions specified in (4) and (5) and flown back in condition between each run.

(e) For each run, the ratio between the UA maximum A-frequency-weighted sound level (LASmax) and the background noise A-weighted sound level must be greater 15 dB(A). If this ratio is not greater than 15 dB(A), the run must be invalidated.

(f) If flying at the reference heights cannot be achieved due to safety considerations or if they do not permit to fulfil condition (e), the test heights must be adapted as long as they remain within the limits prescribed in Noise.UAS.530(c)(4) and Noise.UAS.530(d)(5), or an alternative test site must be chosen to ensure appropriate noise measurements.

(g) Sufficient runs must be performed to ensure that the 90 per cent confidence interval is within L_{AEref_av} ±1.5 dB(A) and L_{Aeqref_av} ±1.5 dB(A) for each reference procedure and to ensure that the test is valid as specified in Noise.UAS.750.

MoC1 Noise.UAS.530 Flight test procedures

TEST MASS TOLERANCE

Most UA designs, which use electric power for propulsion, do not lead to a mass decrease as the test progresses.

However, certain UA designs that are fuel-powered may lead to a decrease in mass as the test progresses. In such cases and in the absence of a specification for the mass correction, to ensure that the UA mass remains greater than or equal to 90 percent of its MTOM for the entire duration of the test, the UA should be landed and refuelled as necessary.

MoC2 Noise.UAS.530 Flight test procedures

EQUAL NUMBER OF TAILWIND AND HEADWIND RUNS FOR THE LEVEL-FLIGHT PROCEDURE

For the level-flight procedure, the test runs must be made in equal numbers with tailwind and headwind components. The test runs should be conducted in pairs of opposite flight direction to ensure similar meteorological conditions and that the influence of wind speed and direction on the measured L_{AE} is minimised.

MoC3 Noise.UAS.530 Flight test procedures

TEST HEIGHT AND SPEED

(a) Differences between UA test and reference heights are adjusted as specified in Subpart G for the difference in sound propagation path lengths (i.e. spherical spreading effect) for both reference procedures and for the difference in the noise event durations for the level-flight procedure. To minimise these adjustments, the target test speed should be set as close as possible to the reference ground speed (V_{GRef}) for the level-flight procedure, and the target test height should be set as close as possible to the reference height (50 m for the level-flight procedure, 25 m for the hover procedure).

(b) The targeted test heights may not be achievable due to excessive background noise.

The ratio between UA sound level and background noise sound level may not be greater than 15 dB(A).

One possible means to improve this ratio is to set the UA at a lower target test height until the criterion of 15 dB(A) is met for each run. To adapt and determine the appropriate target test height, practice runs (not valid for the establishment of noise levels) should be conducted in the configuration as specified in Subpart E. Since variations in measured sound levels of up to ±2.0 dB(A) from run to run may occur, the difference between the UA sound level and background noise sound level should therefore be large enough to accommodate the anticipated quietest UA sound level.

For the level-flight procedure and for some UA designs, the decrease of the target test height might result in situations where the measurement of ground speed with a camera (as suggested in Noise.UAS.550 MoC 2) proves difficult or unreliable, or where the 10 dB(A)-down point of the noise history is too short to be captured for the SLOW-time-weighting. In such a case, the background noise sound level on the test site should be reduced as much as practical and the target test speed should be progressively decreased. The appropriate target test speed should be determined during the pre-test.

In all cases, the UA test height must remain within the boundaries specified in (c)(4) for the level-flight procedure and (d)(4) for the hover procedure. Moreover, the UA must be flown within its allowable operational range based on its design and the local restrictions at the test site.

MoC4 Noise.UAS.530 Flight test procedures

TEST DURATION

For the level-flight procedure, L_{ASmax} will normally occur when the UA is near the position directly above the noise measurement point.
Pre-test runs should be conducted to determine the 10 dB(A)-down period and ensure that this period is adequately captured by the noise measurement system. The UA flight test conditions should be stabilized well before the initial 10 dB(A)-down point and maintained well after the second 10 dB(A)- down point to obtain a valid noise measurement.

IM1 Noise.UAS.530 Flight test procedures

GENERAL

The reference procedures prescribed in Noise.UAS.320 are set to normalize noise measurements to common profiles and conditions. On the other hand, the flight test procedures prescribed in Noise.UAS.530 are rather flexible in terms of allowable height window (e.g.: between 17 m and 150 m for the level-flight procedure or between 12m and 50m for the hover procedure as specified in Noise.UAS.320(c)(4) and Noise.UAS.320(d)(5) respectively), or allowable test weather conditions (Noise.UAS.520). Measured sound levels acquired through the flight test procedures of Noise.UAS.530

must further be adjusted from test conditions to reference conditions through the requirements of Noise.UAS.710.

IM2 Noise.UAS.530 Flight test procedures

NUMBER OF RUNS

Depending on the type of equipment used to obtain spatial positioning or speed measurement, it may not be possible to obtain the values of test height and/or speed in real time. This might lead to situations where the analysis of run validity (in terms of positioning and speed) can only be conducted once the test is complete. If, at the end of this phase, the number of valid runs is found to be lower than the specified minimum number of six, or the 90 per cent confidence interval is outside of L_{AEref_av} ±1.5 dB(A) or L_{Aeqref_av} ±1.5 dB(A), more test runs will have to be performed to fulfil those conditions. It is therefore recommended during the test to conduct additional runs so as to mitigate the risk of having to deploy the complete test equipment again.

IM3 Noise.UAS.530 Flight test procedures

TEST HEIGHT AND SPEED

The requirements of Noise.UAS.530 set allowable boundaries on the test height (in (c)(4) for the level-flight procedure, in (d)(4) for the hover procedure). They should nevertheless not be considered as sufficient to determine the validity of a test run in terms of height. In addition to those requirements, Noise.UAS.710 (a)(3) limits to ±6 dB(A) the total amount of adjustment that can be applied to noise levels to account for the differences between test and reference flight paths and conditions. For this reason, MoC3 Noise.UAS.530 Flight test procedures recommends setting the target test speed as close as possible to V_{GRef}, and the target test height as close as possible to the reference height (50 m for the level-flight procedure, 25 m for the hover procedure).

Additionally, to satisfy the requirement of Noise.UAS.530(c)(2) and ensure that the test height accommodates the UA to fly in a stable condition over the entire 10 dB-downpoint duration, practice flights are strongly recommended prior to the actual test.

IM4 Noise.UAS.530 Flight test procedures

FLIGHT PATH BOUNDARIES

Figure1 IM2 Noise.UAS.530 depicts the specified boundaries of the UA flight path for the two reference procedures.

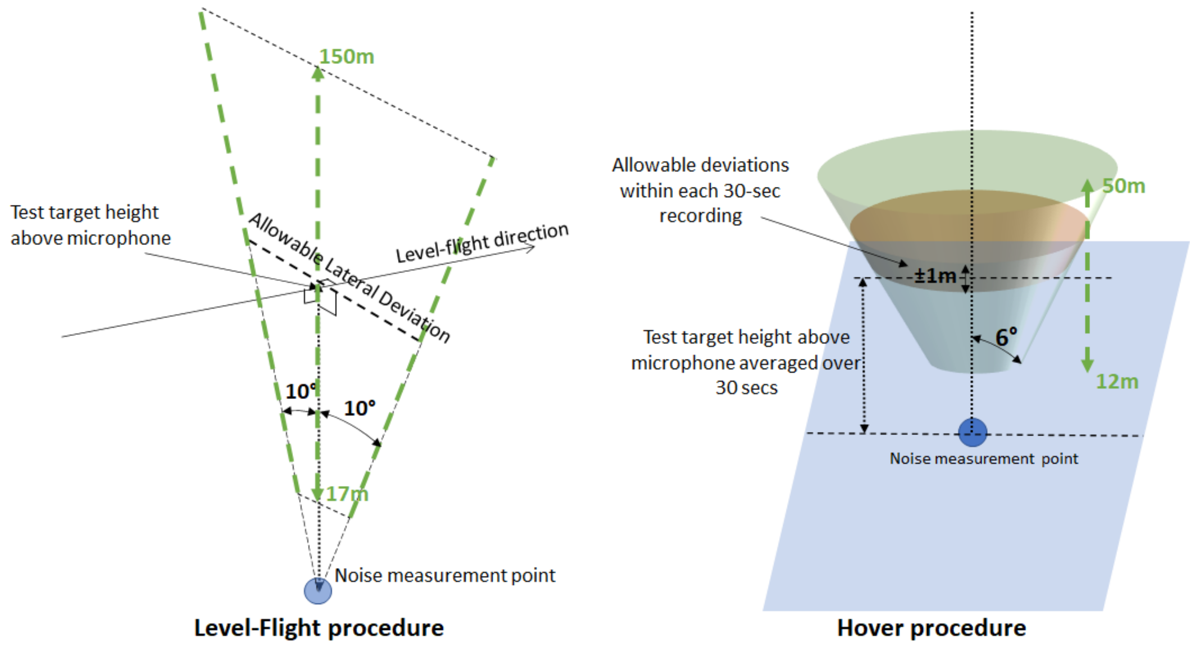

Figure 2: Depiction of flight boundaries for both reference procedures

IM5 Noise.UAS.530 Flight test procedures

HOVER RUNS

Noise.UAS.530(c)(6) requires that, after the 30-second noise recording of every run of the hover test procedure (valid or not), the UA must be flown not only outside of the ±1m height window defined in Noise.UAS.530(c)(5), but also outside of the 3°-cone defined in Noise.UAS.530(c)(4), before being flown back into condition and initiating the next 30-second noise recording. Under no circumstance should a continuous on-condition recording be performed and be later subdivided into 30-second recordings.

Noise.UAS.540 Noise measurement

(a) The sound levels must be measured with a noise measurement system as specified in Subpart F.

(b) The overall sensitivity of the noise measurement system must be checked with the system gain set at levels which will be used for UA noise measurements, using a sound calibrator as specified in Noise.UAS.640 before the test starts, after the test has ended, and at least every hour during the test. UA noise data acquired not preceded and succeeded by such checks must be invalidated. One condition for the noise measurement system to be considered satisfactory is for the difference of acoustical sensitivity levels of the noise measurement system to be less than or equal to 0.5 dB(A) between the checks.

(c) The acoustical signals must be recorded and stored for subsequent analysis using a recording and reproducing system or computer-based system.

(d) Provision must be made for an overload indication to occur during an overload condition on any relevant level range. UA noise data collected during an overload condition of any measurement system components in the signal path prior to and including the recorder are invalid and must not be used.

(e) The A-frequency-weighted sound level of the background noise, which includes the ambient noise and the electrical noise of the measurement systems, must be measured in the test area with the noise measurement system gain set at the levels used during the test.

(f) For the level-flight procedure, the A-weighted sound exposure level must be integrated over the 10 dB(A)-down period as specified in Noise.UAS.220(a). For an integrating sound level meter where the start and stop times are selected manually, the actual integration period must be longer than the true 10 dB(A)-down period.

MoC1 Noise.UAS.540 Noise measurement

SOUND CALIBRATOR CHECKS

The initial, final and periodic checks permit to identify any potential change in the overall sensitivity of the noise measurement system. It is important that the system warm-up time recommended by the noise measurement instruments manufacturer is observed prior to the checks. Sound calibrator(s) should be identified in the test plan.

MoC2 Noise.UAS.540 Noise measurement

NOISE ACQUISITION DURATION

For an integrating sound level meter with manual acquisition start and stop times, the acquisition period must be longer than the true 10 dB(A)-down period but should not be extended longer than a few seconds. This will minimise the effect on the L_{AE} value since the sound levels will be more than 10 dB(A) below the maximum sound level value.

IM1 Noise.UAS.540 Noise measurement

SOUND LEVEL VARIABILITY

The sound levels may vary mainly due to environmental factors and the internal warm-up as recommended for most noise measurement instruments. Occasionally, sound level variations may occur due to cable problems or even equipment damage. A proper check of the overall sensitivity of the noise measurement system permits to identify such occurrences.

Noise.UAS.550 Spatial positioning and speed measurement

(a) The point of the UA that is tracked for the height determination must be carefully identified to ensure a consistent adjustment to the reference height as specified in Noise.UAS.710.

(b) For the level-flight procedure, and for each run, the following must be measured:

    (1) the UA height above the noise measurement point, in the vertical plane perpendicular to the direction of flight;

(2) the UA lateral deviation as specified in Noise.UAS.530;

(3) the UA speed relative to the ground (V_G) above the noise measurement point.

(c) For the hover procedure, and for each run, the following must be measured:

(1) the UA height above the noise measurement point with a sample rate equal to or greater than 1 Hz;

(2) the UA deviation from the axis normal to the ground at the noise measurement point.

(d) The spatial positioning and speed measurement must be carried out using one of the following:

(1) a global navigation satellite system (GNSS) receiver that must be augmented and must be installed on board of the UA independently from the UA built-in navigation system;

(2) a digital camera for photographic scaling that must capture images in a continuous shooting mode.

(e) The spatial positioning and speed measurement instruments must be operated within their environmental limitations as specified by their manufacturer.

MoC1 Noise.UAS.550 Spatial positioning and speed measurement

HEIGHT DETERMINATION

(a) Depending on the spatial positioning and speed measurement method and the UA design, the point of the UA that is tracked for the purpose of height determination could be the location of the GNSS receiver installed on board of the UA for the augmented GNSS tracking method, the geometric centre in the horizontal plane of the propellers or the wings, or the bottom of the test vehicle.

(b) For the hover procedure, the spatial positioning instruments available on the market are normally able to accommodate a 1 Hz sample rate or better for the height measurement.

MoC2 Noise.UAS.550 Spatial positioning and speed measurement

SPATIAL POSITIONING AND SPEED MEASUREMENT METHODS

This MoC provides recommendations on the methods specified to measure the UA spatial positioning over the noise measurement point for both reference procedures and the UA speed relative to the ground (V_G) for the level-flight procedure.

(a) Augmented global navigation satellite system (GNSS)
A GNSS receiver must be installed on board of the UA in addition to the UA built-in navigation system as specified in Noise.UAS.550 to allow appropriate data analysis.

GNSS receivers to obtain time-space-position information are widely available for general use. They utilize signals from established satellite networks such as the EU Galileo system, the Russian global navigation satellite system (GLONASS), and the US NAVSTAR global positioning system (GPS).

However, conventional GNSS receivers are not considered to be sufficiently accurate to obtain time-space-position information for the UA noise test. Experience has shown that some GNSS receivers might exhibit more than 15% error on the height measurement compared to Real-Time Kinematic (RTK) sensors, resulting in significant errors on the final sound levels once adjusted to reference height. For this reason, the GNSS must be augmented as specified in Noise.UAS.550 to improve its accuracy. The following are acceptable augmentation methods:

(1) Differential global navigation satellite system (DGNSS)
A significant improvement in accuracy can be achieved by supplementing the data obtained from the GNSS receiver with data from a second local fixed-position GNSS receiver at a known location. Such an arrangement is referred to as the differential GNSS (DGNSS). In some instances, the local fixed-position GNSS receiver can be installed by the applicant in the vicinity of the noise measurement point. In such a case, its exact position should be properly surveyed by a third point located at known latitude, longitude, and elevation such as a monument. In other instances, the applicant may rely on a ground-based augmentation system (GBAS), which provides access to a set of reference local fixed-position GNSS receivers, and which is very often located in the vicinity of airports.

(2) Satellite-based augmentation systems (SBAS)
SBAS such as the European Geostationary Navigation Overlay Service (EGNOS) provide an augmentation using satellite-broadcast.

(3) Real-time kinematic positioning (RTK)
The RTK method is also based on the principle of differential correction. It uses measurements of the phase of the carrier wave of the GNSS receiver signal in addition to the information contained in this signal. It relies on reference stations and can provide corrections up to centimetre-level accuracy.
More details on recommended practices can be found in Section 3.2.1 of ICAO Doc 9501-Volume I (International Civil Aviation Organization Doc 9501, Environmental Technical Manual, Volume I - Procedures for the Noise Certification of Aircraft, Third Edition, 2018).

(4) Post-processing for methods relying on augmentation systems
The information from the augmentation system may not always be available in real-time and may become available several hours after the end of the test. As such, the UA built-in navigation system will likely be the primary tool used to fly the UA according to the specified procedures.

Extra care should be taken during the installation of any external sensor on the UA that it does not interfere with other UA systems such as the communication between the ground controller and the flying vehicle, or the magnetic compass, as it could prevent proper and safe control of the vehicle. Such risks can be mitigated through sufficient planning and practice runs.

(b) Digital photographic scaling

(1) General
Albeit seemingly less accurate than UA built-in navigation systems, the use of a digital camera for photographic scaling has been proven to deliver only small deviations to Real Time Kinematic systems (c.f. (a)(4)).

The digital photographic scaling is a methodology generally approved for height determination in support of the noise certification of propeller-driven aeroplanes in accordance with Chapter 10 of Amendment 13 to Volume I of Annex 16 to the Chicago Convention. The related guidance material can be found in Section 3.2.2 of

ICAO Doc 9501-Volume I (International Civil Aviation Organization Doc 9501, Environmental Technical Manual, Volume I - Procedures for the Noise Certification of Aircraft, Third Edition, 2018, Amendment No 1).

The applicant should follow the recommendations contained in Section 3.2.2 of ICAO Doc 9501-Voume I for the height determination and for the calibration of the camera. This MoC provides additional recommendations on the determination of the UA ground speed, which requires to take more than one picture.

Note: The guidance material in Section 3.2.2 of ICAO Doc 9501-Volume I is based on SAE Aerospace Information Report AIR902A, (SAE AIR902A "Determination of Distance from Ground Observer to Aircraft for Acoustic Tests", Rev.A, 2017-09). SAE AIR902A provides additional details on the use of digital photographic scaling techniques to determine aircraft height and a worked example of the method for UA.

The applicant should also consider allocating sufficient practice time prior to executing the actual test to sort out the possible following problems:

- Possible noise created by the camera shutter (see point (7)).
- Need to position the camera so as not to intrude into the 75° half angle specified in Noise.UAS.520(b). In case the camera needs to be located further from the measurement points, the applicant can make use of the methodology provided in Section 6.1 of SAE AIR902A.
- Possible prohibition for camera operators to be located directly underneath the flight path for safety reasons. To mitigate this risk, sufficiently long cables or high-range remote controllers can be used to trigger the pictures from a safe distance.

(2) Digital camera

(i) General

The camera with a fixed focal length lens should be used.

The image processing software should allow the identification of individual pixels on an image by row and column (X and Y) coordinates.

The camera should be mounted at a fixed position close to the noise measurement (without obstructing the noise propagation from the UA to the microphone) point such that the centre of the captured image, i.e. the origin of the X and Y axes, is considered as the location of the noise measurement point.

The camera should point vertically upward.

(ii) For the level-flight procedure:

(A) The camera should be located under the expected flight track

(B) When the UA approaches the overhead position relative to the camera system, the operator should capture the images in a continuous shooting mode, at regular and as short as possible time intervals. This manoeuvre should be practiced during pre-test flights such that the operator executes it properly during the noise test. This manoeuvre should be performed under good daylight conditions (not at sunrise or sunset) to allow for a fast shutter speed and a small lens aperture and to obtain a clean image. A fast shutter speed avoids blurred pictures due to the motion of the UA. A small lens aperture increases the depth of field and as such facilitates the focus. Since the position of the UA with respect to the noise measurement point is derived from its size on the captured image, it is paramount that the picture be sharp. Given the heights flown by the UA, the camera focus should be set to infinity to capture the sharpest images.

(iii) For the hover procedure:

(A) The sample rate equal to or greater than 1 Hz, specified in Noise.UAS.550(c)(1), for the measurement of the UA height above the noise measurement point can usually be achieved on most modern cameras either with the use of a remote controller or from the options available in the camera internal menu. As an alternative to the requirement of Noise.UAS.550(c)(1), it is however acceptable to acquire only one picture for the entire 30-second run and control that the height remains within ±1m of the average height through the use of the on-board navigation system.

(B) The pictures should be shot under good daylight conditions (not at sunrise or sunset) for the reasons raised in point (ii).

(3) Height determination

The height determination is based on the geometric principle using the properties of isosceles triangles and described in detail in Section 3.2.2 of ICAO Doc 9501-Volume I.

Figure1 IM2 Noise.UAS.550 and the associated equation illustrate this principle:

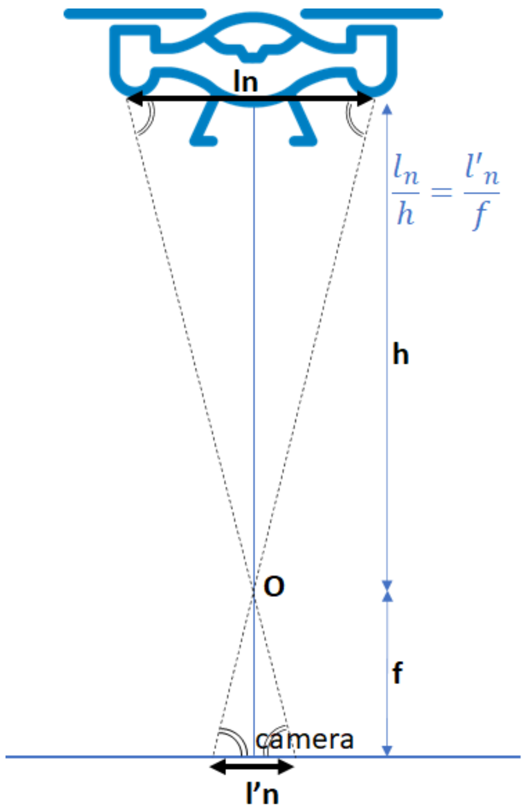

Figure 3: Basic photo-scaling geometry for the determination of UA height

where:

f is the focal length of the digital camera/lens system
h is the height of the UA above the digital camera lens
$l'n$ is the length of the UA on the captured image
ln is the length of the UA normal to the line of sight
O is the location of the focal point of the digital camera
h and ln are of the same unit
f and l'n are of the same unit

The length of the UA does not correspond to any specification and should rather be defined by the applicant according to the UA design. It is recommended to consider the largest distance between two points on the UA that can be distinguished from underneath the UA. For multicopter designs, this length can be the diagonal line between the centre of two opposite rotors. For fixed-wing or powered-lift designs, the wingspan is usually a good candidate.

The camera system units could be different from the physical distance units, such as image pixels, provided that a calibration image captured as described in ICAO Doc 9501-Volume I is used.

The focal length of the digital camera/lens system, f, is the height of the isosceles triangle from the lens to the image and is determined from the calibration as described in ICAO Doc 9501-Volume I. It is not the focal length of the lens. The use of the focal length of the lens would result in noticeable errors.

(4) Lateral distance determination

A similar set-up as in point (3) enables the determination of the lateral distance, i.e. the lateral deviation for the level-flight procedure and the deviation from the normal to the ground for the hover procedure. The lateral distance of the tracked point of the UA, lat,, should be determined from the following formula:

$f / h = lat_{img} / lat$

where:

f is the focal length of the digital camera/lens system
h is the height of the UA above the digital camera lens determined in accordance with point (3)
lat_{img} is the distance between the centre of the captured image and the tracked point of the UA on the image
lat is the ground distance between the location of the camera and the tracked point of the UA vertically projected on the ground.

It is recommended to choose a tracked point located at the geometric centre of the UA. Figure2 IM2 Noise.UAS.550 illustrates the geometry of this determination.

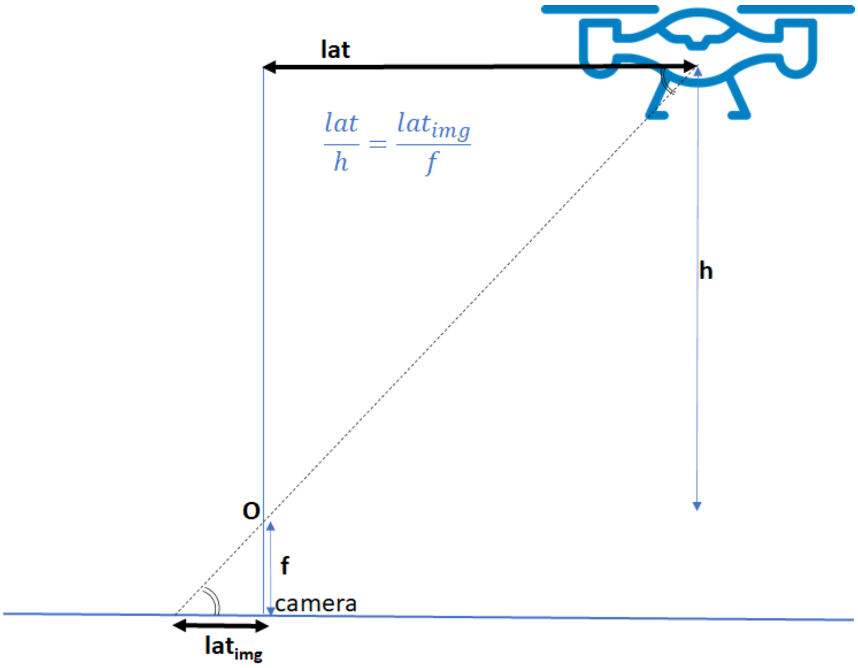

Figure 4: Basic photo-scaling geometry for the lateral distance determination

(5) Ground speed determination for the level-flight procedure

(i) A digital camera with a continuous shooting-mode permits the determination of the ground speed, V_G. The operator should know the time interval between two images that the camera delivers in continuous shooting mode ("burst rate"). This time interval is not the shutter speed. The distance flown by the UA between two images should be determined and the ground speed should be calculated in dividing the distance flown by the time interval as described in point (ii).

(ii) UA ground speed determination

(A) The camera should be oriented such that the image width is aligned with the direction of the UA flight and the UA is entirely within the frame and such that it captures as many pictures as possible.

(B) The applicant may find merit in using an image processing software that allows the blending of all images where the UA appears in the frame into one single image to obtain a result as depicted Figure3 IM2 Noise.UAS.550.

(C) With sufficient practice an operator could conduct the procedure for the ground speed determination in parallel to the height and lateral distance determination. Achieving a good result is a compromise between getting enough images where the UA is in the frame and an image definition good enough to allow for a proper determination of UA height. If this cannot be achieved, the applicant should consider the use of an additional camera to determine the ground speed separately.

(D) The ground speed should be calculated by dividing the ground distance covered by the UA between two images by the "burst rate" of the camera.

(a) The “burst rate” is the time interval between two consecutive images and can usually be set manually by the operator on digital single-lens reflex (DSLR) cameras. A rate of 5 fps (frames per second) or better should be used. This rate is commonly achievable in good light conditions. If the exact value of the burst rate is unknown to the applicant or varies according to the light conditions, the applicant might consider the use of a video camera instead (see (8)).

(b) The actual horizontal distance D_i covered between the instants of consecutive i^{th} and $i+1^{th}$ images should be derived from the following formula:

$$D_i = \frac{D_{i,img}}{f} * {(h_i + h_{i+1})}/{2}$$

where:

f is the focal length of the digital camera/lens system

h_i and h_{i+1} are the heights of the UA above the digital camera lens for both i^{th} and $i+1^{th}$ images , determined in accordance with point (3)

$D_{i,img}$ is the distance between the UA positions on those two images as shown on Figure3 IM2 Noise.UAS.550.

(c) From the knowledge of D_i calculated according to (b) for each set of i^{th} and $i+1^{th}$ images and the shutter speed, the ground speed $V_{G,i}$ between each set of i^{th} and $i+1^{th}$ images can be obtained. The ground speed can then be obtained from the arithmetic average of all the $V_{G,i}$ values.

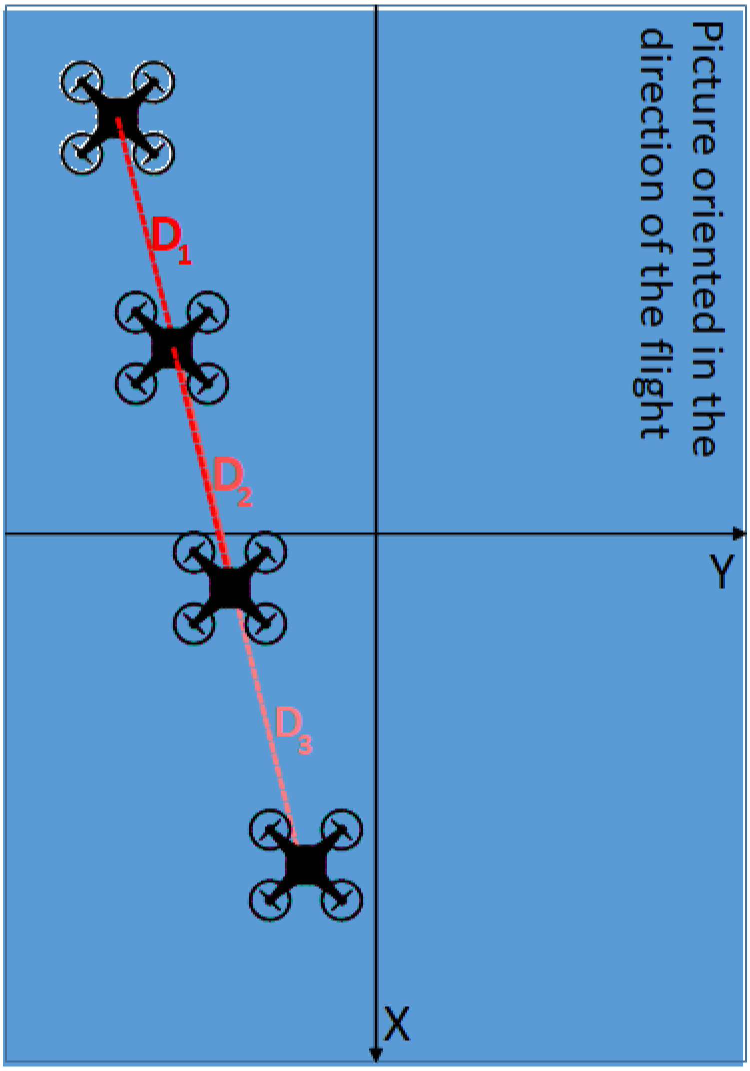

Figure 5: Depiction of the determination of the UA ground speed from a camera in continuous shooting ("burst") mode

(6) Calibration

Each digital camera operated during the noise test and its processing software should be calibrated to determine the focal length of the digital camera/lens system, f, using an object for which the size and distance are known and the following formula:

$f \; / \; d_{object} = l'_{object} \; / \; l_{object}$

where:

- f is the focal length of the digital camera/lens to be determined
- d_{object} is the known distance of the calibration object from the camera lens
- l'_{object} is the length of the calibration object as it appears on the captured image
- l_{object} is the known length of the calibration object normal to the line of sight

The camera should be calibrated before each noise test.

The calibration procedure is described in detail in Section 3.2.2.5 of the ICAO Doc 9501-Volume I.

(i) Calibration set-up

The camera should be calibrated for all digital camera/lens combinations used during the test and with the same settings as the ones used for the determination of height and lateral distances of the UA.
The camera should capture uncompressed images with the highest pixel resolution possible to avoid data compression and aliasing issues.
The camera focus should be set to infinity.

(ii) Calibration procedure

(A) The object chosen for the calibration should:

be visible and on a background that provides a high contrast;
placed away from other discernible objects;
have known dimensions and of nearly the same size as the test UA;
placed at a known distance and far enough to capture a sharp image;
placed such that it appears entirely within the image frame;
placed such that its length, l_{object}, is normal to the line of sight

(B) The operator should:

capture more than one image and choose the most satisfactory;
use the same camera axis as the one that will be used during the test;
capture the calibration object in the centre of the image to avoid lens distortion effects usually prevalent at the edge of the image;
use the same focal distance as expected during the test.

(iii) Images processing

The uncompressed images are processed to determine the length of the calibration object on the images, l'_{object}, in pixels.

(7) Camera shutter sound

Experience has shown that the sound of the camera shutter may interfere with the UA sound levels since the camera should be placed close to the noise measurement point. This interference is exacerbated when the camera is used in continuous shooting mode. This issue could be mitigated by one of the following means:

(A) The camera could be placed further from the noise measurement point. In this case the difference between the origin of the X and Y axes on the image and the noise measurement location should be factored into the determination lateral deviation. As explained in Section 6.1 of SAE AIR902A, a visual reference, such as a suspended horizontal rigid wire above the camera, in a direction perpendicular to the direction of the flight would need to be added. This means should be tested and practiced prior to the actual noise test, especially because an additional wire may complicate the proper detection of the UA on the image.

(B) The camera could be placed in a small enclosure of acoustic wedge panels that prevent the shutter sound from propagating to the microphone. This enclosure should allow an easy access to the camera (change of batteries, etc).

(8) Video camera

As long as the image resolution permits a proper determination of the UA positioning, the general considerations of (1) are respected, the setup of (2) is applied, and the calibration procedure of (6) is followed, the determination of height, lateral distance and ground speed can be determined according to (3), (4) and (5) with a video camera. Especially, for the determination of the ground speed according to the procedure described in (5), the use of video will allow a fixed and known time interval between two frames (e.g.; 24 fps) that will not depend on light conditions and will permit an accurate determination of time intervals between images.

IM1 Noise.UAS.550 Spatial positioning and speed measurement

AUGMENTED GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS)

As indicated in MoC2 Noise.UAS.550 (Spatial positioning and speed measurement) (a)(4), when using augmented GNSS to obtain spatial positioning and speed measurement of the UA, the UA built-in navigation system will likely be the primary tool used to fly the UA according to the specified procedure, while the data acquired from the DGNSS might only be available after completion of the test. This may lead to situations where runs, which would be deemed valid according to the UA built-in navigation system, will have to be rejected, and may require to deploy the complete test equipment again in case there would not be enough valid runs. The applicant may find merit in conducting pre-test flights to evaluate possible systematic offsets between results obtained with the UA built-in navigation system and results obtained with the augmented GNSS.

SUBPART F – NOISE TEST EQUIPMENT

Noise.UAS.610 Noise measurement system

(a) The noise measurement system must comply with the specifications in this Subpart and must consist of the following equipment:
   (1) a microphone designed to have uniform frequency response for sound incident on the diaphragm from random directions, or in the pressure field of a closed cavity;
   (2) a microphone installation and mounting hardware that minimizes interference with the sound to be measured;
   (3) a recording and reproducing equipment to store the measured UA noise signals for subsequent analysis.

(b) The noise measurement instruments must be operated within their environmental limitations as specified by their manufacturer.

(c) The characteristics of the noise measurement system regarding directional response, SLOW time weighting, level linearity, A-frequency weighting, and response to short-duration signals must comply with the Class 1 noise measurement instruments as specified in the IEC 61672-1 ("Electroacoustics — Sound level meters — Part I: Specifications", 2002).

Noise.UAS.620 Microphone characteristics and set-up

(a) The microphone must be:

(1) a 12.7 mm diameter pressure type,

(2) protected with a grid,

(3) mounted in an inverted position such that the microphone diaphragm is 7 mm above and parallel to a ground plate as specified in (b).

(b) A white-painted circular metal plate must be placed horizontally on the ground, and flush with the surrounding ground surface. The ground below the plate must have no cavities.
The plate must have a diameter of 40 cm and must be at least 2.5 mm thick.

(c) For the level-flight procedure, the microphone must be located 15 cm from the centre of the circular plate along a radius normal to the line passing through the centre of the circular plate in the direction of the UA flight path.

(d) If a windscreen is used to minimise wind- and turbulence-induced pseudo-sound levels and to protect the microphone, care must be taken to preserve the original acoustical characteristics of the windshield. If the windscreen is made from a commercially available spherical foam windscreen and cut into a hemispherical shape to accommodate the microphone over the plate, the cutting process must not damage the cut surface and the microphone must be inserted to comply with the specified set-up.

MoC1 Noise.UAS.620 Microphone characteristics and set-up

MICROPHONE CONFIGURATION AND INSTALLATION

(a) Ground plane microphone configuration and microphone sensitivity

The specified ground plane microphone configuration greatly minimizes the interference effects of reflected sound waves inherent in pole-mounted microphone installations. The specified ground plane configuration places the microphone diaphragm into an effective sound pressure field for the frequency range of interest. Microphones designed for uniform pressure response are appropriate for use in such installations.

(b) Inverted microphone set-up

The inverted microphone set-up shown in Figure1 IM1 Noise.UAS.620 is an example of the design and construction of the microphone holder and the ground plate. The legs of the microphone holder should be firmly attached to the plate so that the microphone holder does not vibrate during the test. The plate is painted white to reflect the sun's rays and reduce the thermal effects on the microphone diaphragm. A metal spacer that has a thickness of 7 mm minus the space between the microphone protective grid and the microphone diaphragm is a practical tool to use in setting the space between the microphone diaphragm and the ground plate.

The spacing of the microphone diaphragm relative to the plate is critical. For frequencies of interest (50 Hz to 10 kHz), 7 mm spacing has been determined to provide the best compromise of associated technical considerations.

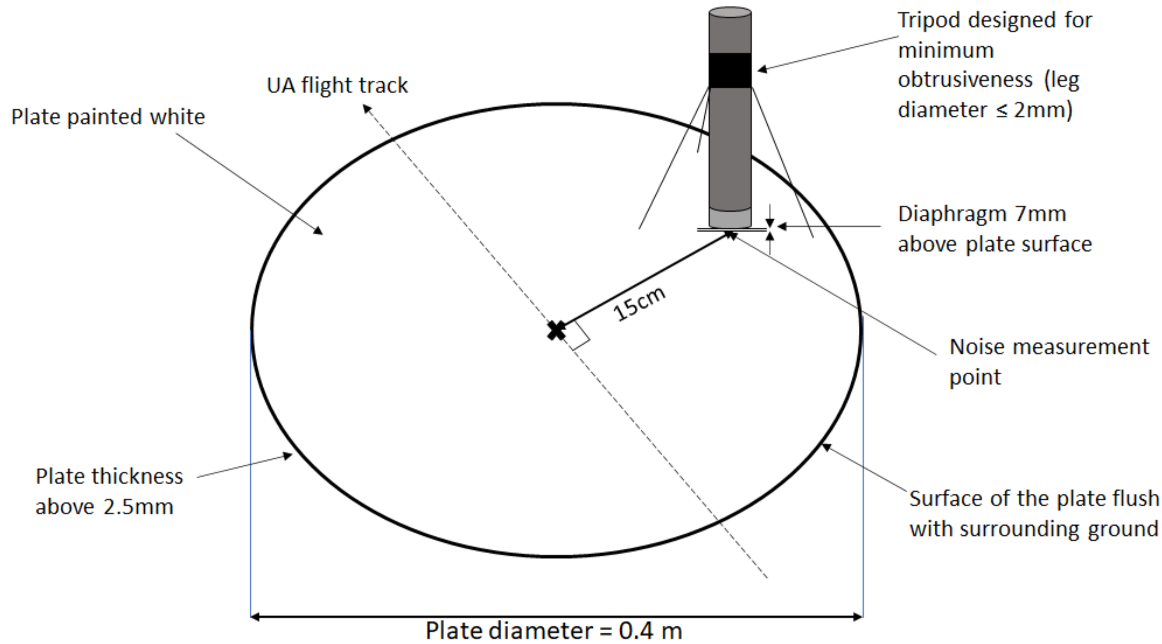

Figure 6: Example of an inverted microphone set-up

(c) Ground plate installation in local ground surface
Care should be taken during the installation of the ground plate to ensure that the ground surface beneath the plate is level and contains no voids or gaps. One way to achieve this is by pressing the plate into the ground surface at the desired location, applying slight pressure, then removing the plate to determine if any areas under the plate are recessed. If necessary, the recesses should be filled in with loose material, such as sand or soil, to obtain a level, uniform underlying surface. Care should also be taken to ensure that the edges of the plate are flush with the surrounding ground surface. This is especially important for plates that are thicker than the specified minimum of 2.5 mm. In some cases, it may be appropriate to moisten the soil with water immediately before installation to allow the surface to mould itself around the plate. In such cases, noise measurements should not be performed until the ground has dried.

(d) Design and construction of the microphone support
The microphone support should be designed so that it minimizes any potential interference with sound waves from the UA arriving in the vicinity of the microphone. If a spider-like structure such as that in Figure1 IM1 Noise.UAS.620 is used, the number of legs should be limited to three. As specified in the figure, the legs should be no larger than 2 mm in diameter. Ideally the support collar should be as small as possible, and it should also implement some sort of tightening device, such as a set screw, to facilitate adjustment of the microphone diaphragm height above the plate. The support should be stable and should orient the microphone in such a way that the diaphragm is parallel to the plate.

(e) Microphone cable support
In some cases, it may be desirable to provide additional support to the microphone cable as it leads away from the plate. A metal rod or similar sort of support may be used for this purpose.

Any such support should be as small as possible and located as far away from the plate as is practical. The microphone cable should lead away from the plate as directly as possible.

(f) Windscreen
A windscreen may be used when wind speed exceeds 2.6 m/s in cases where these wind speeds are within the acceptable weather window.
A windscreen made from a commercially available spherical foam windscreen and cut into a hemispherical shape to accommodate the microphone over the plate would normally have no significant effect on the measured sound levels.
Condensed water or solid particles clogged on a foam windshield alter its acoustical characteristics.

(g) Hover procedure
The same setup can be used for the hover procedure.

(h) Safe operating distance from the noise measurement point
In some instances, safety considerations may prevent operators from standing under the UA flight path. In such cases, long cables, or possibly remote controllers, can be used that enable the operator to trigger and monitor noise recordings or check the signal-to-noise ratio requirements specified in Noise.UAS.530(e) from a safe distance.

Noise.UAS.630 Recording and reproducing equipment

(a) The A-weighted frequency sound level must be directly measured from an integrating sound level meter.
(b) The acoustical signals must be stored using a recording and reproducing system or computer-based system both with a permanent data storage device. The recording and reproducing systems must comply with the specifications in Subpart F at the recording speeds, data sampling rates, the frequency bandwidths and recording channels selected and used for the test.
(c) The applicant must seek the approval from the Agency before choosing the following method as an alternative to (b): storage of the acoustical signal on a digital audio recorder for subsequent determination of the A-weighted frequency sound level.

MoC1 Noise.UAS.630 Recording and reproducing equipment

SOUND LEVEL METERS

The noise recording resulting from the use of a sound level meter depends on the design features of the instrument. Digital units capable of storing entire time-histories of sound levels for multiple runs are now widely available and should be used. They enable those time-histories to be recalled to the instrument's display or downloaded to a computer. Modern sound level meters are capable of audio recording as well as noise analysis and offer the advantage of a compact all-in-one solution.

An audio recorder can be used to preserve a complete acoustical record of the events. If there are questions about the data observed during the test, the recorded data can be replayed multiple times if necessary, to verify the results.

Noise.UAS.640 Sound calibrator

(a) The sound calibrator used for checking the overall sensitivity of the noise measurement system as specified in Noise.UAS.540 must:

(1) comply with the Class 1 requirements of IEC 60942 ("Electroacoustics — Sound calibrators", 2003);

(2) generate a known sound pressure level using sine wave signals at a known frequency.

(b) The sound calibrator output must have been determined by a standardizing laboratory within 6 months of each noise test. Changes in the output of the sound calibrator must be less than or equal to 0.2 dB to its nominal output value. The sound calibrator cannot be used if any of those two requirements is not satisfied.

SUBPART G – COMPLIANCE PROCEDURE

Noise.UAS.710 Adjustments of the measured sound levels

(a) General

(1) The measured sound levels must be adjusted to account for the difference between the test procedures and conditions and the reference procedures and conditions as defined in Subpart C, and in particular, to account for the following effects:

(i) the difference in the sound propagation path lengths between the actual flight path of the test UA and the reference flight path;

(ii) the difference in the noise event durations for the level-flight procedure between the path of the test UA and the reference path;

(iii) the difference in airspeeds between the test and reference conditions for the level-flight procedure;

(iv) difference in the atmospheric absorptions between meteorological test conditions and reference conditions.

(2) For each run the measured sound level must be adjusted to account for the effects listed in point (1) and to obtain the reference sound level by adding components as follows:

(i) For the reference level-flight procedure:

$$L_{AEref,i} = L_{AE,i} + \Delta_{1,i} + \Delta_{2,i} + \Delta_{3,i} + \Delta_{4,i}$$

where

— $L_{AEref,i}$ is the reference sound level of the i^{th} run

— $\Delta_{1,i}$ is the adjustment component for the difference in sound propagation path lengths for the i^{th} run,

— $\Delta_{2,i}$ is the adjustment component for the difference in the noise event durations for the i^{th} run,

— $\Delta_{3,i}$ is the adjustment component for the difference in airspeeds for the i^{th} run,

— $\Delta_{4,i}$ is the adjustment component for the difference in the atmospheric absorptions for the i^{th} run

— $\Delta_{1,i} + \Delta_{2,i} + \Delta_{3,i} + \Delta_{4,I}$ is the adjustment value for the i^{th} run .

(ii) For the reference hover procedure:

$$L_{Aeqref,j} = L_{Aeq,j} + \Delta_{1,j} + \Delta_{4,j}$$

where

- $L_{Aeqref,j}$ is the reference sound level of the j^{th} run
- $\Delta_{1,j}$ is the adjustment component for the difference in sound propagation path lengths for the j^{th} run,
- $\Delta_{4,j}$ is the adjustment component for the difference in the atmospheric absorptions for the j^{th} run
- $\Delta_{1,j} + \Delta_{4,j}$ is the adjustment value for the j^{th} run .

(3) For each run, the adjustment value as defined in point (2) must not exceed 6 dB(A).

(b) The adjustment component for the difference in the sound propagation path lengths accounts for the spherical spreading and must be calculated as follows:

(1) for the level-flight procedure:

$$\Delta_{1,i} = 20 \log_{10} (H_i / 50)$$

where:

- H_i is the height, in meters, of the centre of gravity of the test UA when directly over the noise measurement point of the i^{th} run;
- H_i is obtained after correction of the height to account for the difference between the point of the UA that is tracked and the centre of gravity of the UA.

(2) for the hover procedure:

$$\Delta_{1,j} = 20 \log_{10} (H_j / 25)$$

where:

- H_j is the height, in meters, of the centre of gravity of the test UA when directly over the noise measurement point of the j^{th} run;
- H_j is obtained after correction of the height to account for the difference between the point of the UA that is tracked and the centre of gravity of the UA.

(c) The adjustment component for the difference in the noise event durations must be calculated as follows:

$$\Delta_{2,i} = -7.5 \log_{10}(H_i / 50) + 10 \log_{10} (V_{G,i} / V_{Gref})$$

where:

H_i is the height, in meters, of the centre of gravity of the test UA when directly over the noise measurement point of the i^{th} run;

H_i is obtained after correction of the height to account for the difference between the point of the UA that is tracked and the centre of gravity of the UA;

$V_{G,i}$ is the ground speed of the test UA, in meters per second, measured over the noise measurement point at the i^{th} run;

V_{Gref} is the reference ground speed above the noise measurement point, in meters per second, defined in Noise.UAS.320.

(d) The adjustment component for the difference in the airspeeds must be calculated as follows:

$$\Delta_{3,i} = K_3 \log_{10} (V_{Aref} / V_{A,i})$$

where:

— $V_{A,i}$ is the true airspeed of the test UA
— $V_{A,i}$ is calculated as follows:
— $V_{A,i} = V_{G,I} + V_{10} \cos(\alpha_{wind,i} + \alpha_{UA,i})$
Where:
- $V_{G,i}$ is the ground speed of the test UA, in meters per second, measured over the noise measurement point at the i^{th} run;
- V_{10} is the wind speed measured at 10 m above the ground level (V_{10}), in meters per seconds;
- $\alpha_{wind,i}$ is the wind direction ***where the wind is coming from*** measured during the i^{th} level-flight run;
- $\alpha_{UA,i}$ is the direction of flight ***towards where the UA is heading*** during the i^{th} level-flight run.

If the wind speed at the i^{th} run($V_{w,i}$) is measured at a height lower than 10 meters ($H_{w,i}$), the wind speed at 10 m ($V_{10,i}$) must be approximated by the following formula:

$$V_{10,\mathrm{i}} = V_{w,i} \cdot \left(\frac{10}{H_{w,i}}\right)^{0.14}$$

— V_{Aref} is the reference true airspeed and is considered equal to the reference ground speed V_{Gref} defined in Noise.UAS.320.;
— K3 is a coefficient equal to 25, unless the applicant choses to determine another value of K3 through appropriate testing that must be approved by the Agency and that:
   o isolates the effect of airspeed by initially adjusting the measured sound levels for the differences in the sound propagation path lengths, the noise event durations and the atmospheric absorptions;
   o provides a statistically significant number of test points over a satisfactory speed range.

(e) The adjustment component for the difference in the atmospheric absorptions accounts for the difference in the temperature and the relative humidity between the test and the reference atmospheric conditions. This adjustment component is a noise penalty that must be determined for each run in accordance with points (2) and (3), unless the combined values of temperature and relative humidity for each run are within the "no-correction window" as defined in point (1).
   (1) The "no-correction window" is defined as follows:
      (i) For the reference level-flight procedure:
         (A) $T_i \geq 5°C$ and $T_i \leq 35°C$;
         (B) $RH_i \geq 23\%$ and $RH_i \leq 90\%$; and
         (C) $T_i \geq -7.84 \times 10^{-5} \times RH_i^3 + 1.795 \times 10^{-2} \times RH_i^2 - 1.65 \times RH_i + 64.36$ for RH_i between 23% and 87%

where:

— RH_i is the relative humidity at the i^{th} run in %

— T_i the temperature in °C at the i^{th} run.

(ii) For the reference hover procedure:

(A) $T_j \geq 5°C$ and $T_j \leq 35°C$;

(B) $RH_j \geq 23\%$ and $RH_j \leq 90\%$; and

(C) $T_j \geq -7.84 \times 10\text{-}5 \times RH_j^3 + 1.795 \times 10^{-2} \times RH_j^2 - 1.65 \times RH_j + 64.36$ for RH_j between 23% and 87%

where:

RH_j is the relative humidity at the j^{th} run in %

T_j the temperature in °C at the j^{th} run.

(2) For the reference level-flight procedure:

(i) $\Delta_{4,i}$ is equal to 0.1 dB(A) when:

(A) $T_i < -7.84 \times 10^{-5} \times RH_i^3 + 1.795 \times 10^{-2} \times RH_i^2 - 1.65 \times RH_i + 64.36$

for RH_i between 23% and 87%; and

(B) $T_i \geq -1.03 \times 10^{-4} \times RH_i^3 + 2.14 \times 10^{-2} \times RH_i^2 - 1.798 \times RH_i + 64.27$

for RH_i between 21% and 79%.

(ii) $\Delta_{4,i}$ is equal to 0.2 dB(A) when:

(A) $T_i < -1.03 \times 10^{-4} \times RH_i^3 + 2.14 \times 10^{-2} \times RH_i^2 - 1.798 \times RH_i + 64.27$

for RH_i between 21% and 79%; and

(B) $T_i \geq -1.318 \times 10^{-4} \times RH_i^3 + 2.50 \times 10^{-2} \times RH_i^2 - 1.94 \times RH_i + 63.85$

for RH_i between 20% and 71%.

(iii) $\Delta_{4,i}$ is equal to 0.3 dB(A) when:

(A) $T_i < -1.318 \times 10^{-4} \times RH_i^3 + 2.50 \times 10^{-2} \times RH_i^2 - 1.94 \times RH_i + 63.85$

for RH_i between 20% and 71%; and

(B) $T_i \geq -1.65 \times 10^{-4} \times RH_i^3 + 2.87 \times 10^{-2} \times RH_i^2 - 2.07 \times RH_i + 63.2$

for RH_i between 20% and 64%.

(iv) $\Delta_{4,i}$ is equal to 0.4 dB(A) when:

(A) $T_i < -1.65 \times 10^{-4} \times RH_i^3 + 2.87 \times 10^{-2} \times RH_i^2 - 2.07 \times RH_i + 63.2$

for RH_i between 20% and 64%; and

(B) $T_i \geq -2.43 \times 10^{-4} \times RH_i^3 + 3.6 \times 10^{-2} \times RH_i^2 - 2.3 \times RH_i + 63.58$

for RH_i between 20% and 56%.

where:

— $\Delta_{4,i}$ is the adjustment component for the difference in the atmospheric absorptions for the i^{th} run;

— RH_i is the relative humidity at the i^{th} run in %;

— T_i the temperature at the i^{th} run in °C.

(3) For the reference hover procedure:

(i) $\Delta_{4,j}$ is equal to 0.05 dB(A) when:

(A) $T_j < -7.84 \times 10^{-5} \times RH_j^3 + 1.795 \times 10^{-2} \times RH_j^2 - 1.65 \times RH_j + 64.36$

for RH_j between 23% and 87%; and

(B) $T_j \geq -1.03 \times 10^{-4} \times RH_j^3 + 2.14 \times 10^{-2} \times RH_j^2 - 1.798 \times RH_j + 64.27$

for RH_j between 21% and 79%.

(ii) $\Delta_{4,j}$ is equal to 0.1 dB(A) when:

(A) $T_j < -1.03 \times 10^{-4} \times RH_j^3 + 2.14 \times 10^{-2} \times RH_j^2 - 1.798 \times RH_j + 64.27$

for RH_i between 21% and 79%; and

(B) $T_j \geq -1.318 \times 10^{-4} \times RH_j^3 + 2.50 \times 10^{-2} \times RH_j^2 - 1.94 \times RH_j + 63.85$

for RH_j between 20% and 71%.

(iii) $\Delta_{4,j}$ is equal to 0.15 dB(A) when:

(A) $T_j < -1.318 \times 10^{-4} \times RH_j^3 + 2.50 \times 10^{-2} \times RH_j^2 - 1.94 \times RH_j + 63.85$

for RH_j between 20% and 71%; and

(B) $T_j \geq -1.65 \times 10^{-4} \times RH_j^3 + 2.87 \times 10^{-2} \times RH_j^2 - 2.07 \times RH_j + 63.2$

for RH_j between 20% and 64%.

(iv) $\Delta_{4,j}$ is equal to 0.2 dB(A) when:

(A) $T_j < -1.65 \times 10^{-4} \times RH_j^3 + 2.87 \times 10^{-2} \times RH_j^2 - 2.07 \times RH_j + 63.2$

for RH_j between 20% and 64%; and

(B) $T_j \geq -2.43 \times 10^{-4} \times RH_j^3 + 3.6 \times 10^{-2} \times RH_j^2 - 2.3 \times RH_j + 63.58$

for RH_j between 20% and 56%.

where:

— $\Delta_{4,j}$ is the adjustment component for the difference in the atmospheric absorptions for the j^{th} run;
— RH_j is the relative humidity at the j^{th} run in %
— T_j the temperature at the j^{th} run in °C.

IM1 Noise.UAS.710 Adjustments of the measured sound levels

ATMOSPHERIC CONDITIONS FOR THE NOISE PENALTIES Δ_4

Figure1 IM1 Noise.UAS.730 illustrates the atmospheric conditions for the no-correction window (Blue) and for the determination of the adjustment component Δ_4 (from a low noise penalty to a high noise penalty in Green, Yellow, Orange and Red) within the allowable test conditions.

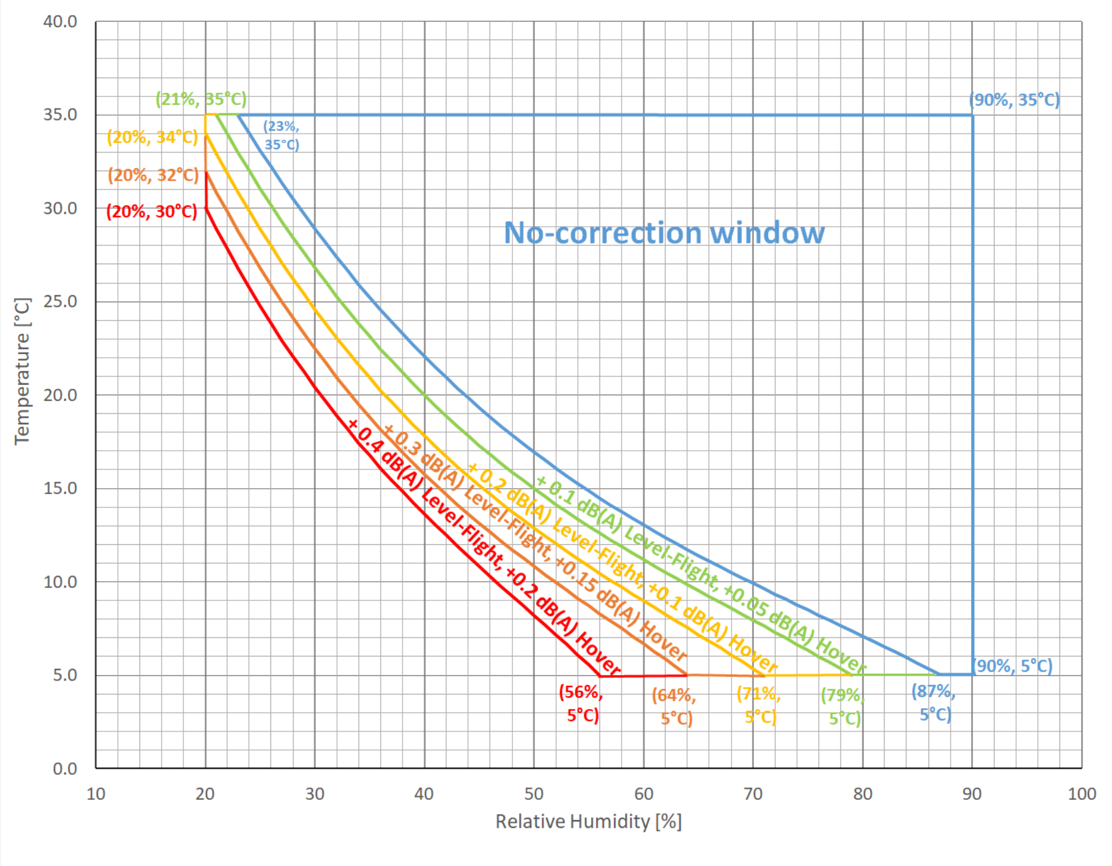

Figure 7: adjustment window for the effect of atmospheric absorption

Noise.UAS.750 Compliance

(a) The 90 per cent confidence interval must be within L_{AEref_av} ±1.5 dB(A) and L_{Aeqref_av} ±1.5 dB(A) respectively.

(b) For the level-flight procedure:

(1) The arithmetic average sound level, L_{AEref_av}, must be calculated from all reference sound levels, $L_{AEref,i}$, as follows:

$$L_{\text{AEref\_av}} = \frac{1}{n}\left\{\sum_{i=1}^{n} L_{\text{AEref,i}}\right\}$$

where $L_{AEref,i}$ is the reference sound level of the i^{th} run over the n valid runs

(2) The 90 per cent confidence interval, CI_ L_{AEref_av}, must be calculated for the average sound level, L_{AEref_av}, using the Student's t-distribution for all reference sound levels, $L_{AEref,i}$, with the following formula:

$$CI\_L_{\text{AEref\_av}} = L_{\text{AEref\_av}} \pm t_{(95,\zeta)} \frac{s\_L_{\text{AEref\_av}}}{\sqrt{n}}$$

where:

$t_{95,\zeta}$ is the 95^{th} percentile of the single-sided Student's t-distribution and depends on the degree of freedom ζ, where ζ = n-1

$s\_L_{\text{AEref\_av}} = \sqrt{\frac{\sum_{i=1}^{n}(L_{\text{AEref,i}} - L_{\text{AEref\_av}})^2}{n-1}}$ is the estimate of the standard deviation associated to L_{AEref_av}

n is the number of valid runs

(c) For the hover procedure:

(1) The arithmetic average sound level, L_{Aeqref_av}, must be calculated from all reference sound levels, $L_{Aeqref,j}$, as follows:

$$L_{Aeqref\_av} = \frac{1}{m}\left\{\sum_{j=1}^{m} L_{Aeqref,j}\right\}$$

where $L_{Aeqref,j}$ is the reference sound level of the jth run over the m valid runs

(2) The 90 per cent confidence interval, CI_ L_{Aeqref_av}, must be calculated for the average sound level, L_{Aeqref_av}, using the Student's t-distribution for all reference sound, $L_{Aeqref,j}$, with the following formula:

$$CI\_L_{Aeqref\_av} = L_{Aeqref\_av} \pm t_{(95,\zeta)} \frac{s\_L_{Aeqref\_av}}{\sqrt{m}}$$

where:

$t_{95,\zeta}$ is the 95th percentile of the single-sided Student's t-distribution and depends on the degree of freedom ζ, where ζ = m-1

$s\_L_{Aeqref\_av} = \sqrt{\frac{\sum_{j=1}^{m}(L_{Aeqref,j} - L_{Aeqref\_av})^2}{m-1}}$ is the estimate of the standard deviation associated to L_{Aeqref_av}

m is the number of valid runs

IM1 Noise.UAS.750 Computation

90 PER CENT CONFIDENCE INTERVAL

(a) The sound levels that are adjusted are measured under conditions as similar as possible for each reference procedure. However, the individual sound levels are not identical due to the measurement variability. The 90% confidence interval provides the range in which the unknown true average value of the sound level can be found with a 90% confidence level.

(b) Since the sound levels are obtained under conditions as similar as possible, they are assumed to constitute a random sample of a normally distributed population with a true mean population and a standard deviation. However, since the number of measured sound levels is small the Student's t-distribution is used instead of the normal distribution to calculate the 90% confidence interval.

(c) The values of the 95th percentile of the single-sided Student's t-distribution, $t_{.95,\zeta}$, as a function of the degree of freedom, ζ, for a 90% confidence interval are listed below:

ζ	$t_{.95,\zeta}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
12	1.782
14	1.761
16	1.746
18	1.734
20	1.725
24	1.711
30	1.697
60	1.671
>60	1.645

SUBPART H – REPORTING

Noise.UAS.810 Noise data

(a) The applicant must report the following noise data to the Agency:

(1) For the reference level-flight procedure, the following data calculated as specified in Noise.UAS.750:

(i) the reference ground speed V_{Gref};

(ii) the average sound levels L_{AEref_av};

(iii) the related 90 per cent confidence interval CI_ L_{AEref_av};

(2) For the reference hover procedure, if applicable, the following data calculated as specified in Noise.UAS.750 :

(i) the average sound levels L_{Aeqref_av};

(ii) the related 90 per cent confidence interval CI_ L_{Aeqref_av};

(b) The applicant must report the following noise data to the Agency:

(1) for each i^{th} valid run the level-flight procedure:

(i) the measured sound levels $L_{AE,i}$ and reference sound levels $L_{AEref,i}$;

(ii) the details of the adjustment calculations carried out as specified in Subpart G;

(2) for each j^{th} valid run of the hover procedure, if applicable:

(i) the measured sound levels $L_{Aeq,j}$ and reference sound levels $L_{Aeqref,j}$;

(ii) the details of the adjustment calculations carried out as specified in Subpart G. If the photographic scaling method of Noise.UAS.550 (d)(2) is used, the photographs used in the determination of the UA position must be included.

Noise.UAS.820 UA information

The applicant must report the following information related to the test UA to the Agency:

(a) The type, model and serial numbers, if applicable, of the UA and the rotors or propellers;
(b) The number of blades and the blade diameter of the rotors or propellers;
(c) The flight software version, or any identifier of the operational envelope of the UAS;
(d) The gross dimensions of UA;
(e) The location of the rotors;
(f) The UA MTOM;
(g) The value of V_{Gref} for the level-flight procedure;
(h) The identification of the UA point being tracked for the UA positioning;
(i) For each i^{th} run of the level-flight procedure:
 (1) The UA height H_i at the closest point to the vertical above the noise measurement point for;
 (2) The UA lateral deviation;
 (3) The UA ground speed ($V_{G,i}$);
 (4) The engine performance parameters, if available.
(j) For each j^{th} run of the hover procedure, if applicable:
 (1) The arithmetic average of the UA height H_i measured above the noise measurement point over the noise acquisition period, and the largest vertical deviation to H_i recorded during that time period;
 (2) the maximum UA deviation from the normal to the ground at the noise measurement point recorded during the noise acquisition period;
 (3) The engine performance parameters, if available.

Noise.UAS.830 Additional test information

The applicant must report the following additional test information to the Agency:

(a) For each run:
 (1) The temperature;
 (2) The relative humidity;
 (3) The average wind speed and the average wind direction;
 (4) The atmospheric pressure;
(b) for each rejected run, a short description of the reason for the rejection;
(c) the type of equipment used for the measurement and analysis of the sound levels;
(d) The type of meteorological instruments used during the test;;
(e) A description of the local topography, ground cover, and any event that might interfere with the sound level recording.