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Applicability of ISO standard 3744 to UA

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Abstract

Unmanned Aircraft Systems (UAS) are used for a variety of purposes. Especially the industrial or professional use of unmanned aircraft (UA) will lead to an increasing number of possible applications. The steadily rising number of UA raises the question of noise impact on the society from these vehicles.

For the first time, an EU regulation provides a uniform noise rating for UA. It involves the introduction of a label for the guaranteed sound power level. This level is to be determined via EN ISO 3744:2010 by means of an enveloping surface method. Manufacturers are required to document the guaranteed sound power level as part of their CE marking. In addition, the EU regulation specifies a maximum permissible sound power level. The permitted level depends on the weight of the UA.

Therefore, the German Environment Agency has started with acoustic investigations of UA. Various small multicopter) were used for the measurements in accordance with the EU regulation. This paper presents the results of the measurements and shows whether the requirements of the EU regulation are complied with. The challenges for users of the applicable measurement standard are also highlighted.

Keywords: UA, UAS, noise, measurements, regulation

1 Introduction

More and more people are using unmanned aircraft (UA), both privately and commercially. While initially the focus was primarily on photography and video, today's applications are much more diverse. UA are used for inspection and maintenance work on e.g. infrastructure, for survey tasks or transporting medical goods. As a result, UA will be increasingly used in the future, not least because longer flight times and larger payloads will become possible.

The steadily increasing number of UA raise the question of expected noise effects. It is foreseeable that more and more people will feel annoyed by the noise of UA flights in the future. However, at present, there are no sound findings on this topic, either nationally or internationally.

The Commission Delegated Regulation 2019/945 [1] includes a noise measurement procedure to label UA similar to the Outdoor Directive 2000/14/EC [2]. This means that the guaranteed sound power level must be displayed on the device or packaging of the UAS. As far as the authors are aware, no practical measurements following the referenced noise measurement procedure has been reported in the literature so far. Therefore, this paper aims at investigating the measurement procedures presented in reference [1] in a practical test setup. Additionally, the paper attempts to identify and highlight practical issues of measurement procedure.

2 Measurement Setup

In its Annex Part 13, reference [1] specifies a noise test specification for recording and calculating the sound power level for UA classes C1-3 and C5-6 in the Open Category. EN ISO 3744:2010 [3] is to be used as the basic standard for the measurement. This standard presents procedures to be used for determining the sound power level of a noise source from sound pressure levels. An enveloping surface enclosing the noise source shall be formed. The measurements are to be carried out in an environment, that approximates acoustic free field conditions in the vicinity of one or more reflecting surfaces.

According to reference [1], the enveloping surface shall be a hemisphere with the microphone arrangements from [3] Annex F. For our measurement we used 12 microphones. The individual microphone positions were calculated as per [3] Annex F. Similarly, the UA is to be measured above a reflective surface, and the rest of the measurement environment must meet the requirements of [3] Annex A.

The measurements took place outdoors at two different airfield sites (see Figure 1 and Figure 2). Runways and taxiways of the airfield were chosen as the reflecting surface in each case. The remaining measurement environment was a spacious lawn without any tree cover or buildings. Further reflections could therefore be excluded.

Figure 1: Setup at the National Experimental Test Center for Unmanned Aircraft Systems (DLR) in Cochstedt/Germany

Figure 2: Setup on the model airfield of the model flying club "Hugo Junkers" Dessau-Rodleben/Germany

Based on the sizes of the measured UA (see Table 1), the smallest possible radius of the microphone hemisphere of 4 m was assumed from [3] Annex F and the microphone positions were determined accordingly. The smallest radius was also chosen to make the difference between extraneous noise and UA noise as large as possible.

Table 1: Specification of the used UA models

	UA 1	**UA 2**	**UA 3**	**UA 4**	**UA 5**	**UA 6**	**UA 7**	**UA 8**
weight in g	7000	6200	10000	1320	499	6200	2355	1700
size in cm	162 x 162 x 78	125 x 125 x 58	170 x 170 x 80	38.3 x 38.5 x 24	33 x 38 x 6	96 x 96 x 50	89 x 89 x 22	42 x 42 x 21
construction type	Octo-copter	Octo-copter	Octo-copter	Quadro-copter	Quadro-copter	Hexa-copter	Quadro-copter	Quadro-copter
theoretical class*	C3	C3	C3	C2	C1	C3	C2	C2

*This corresponds to the Open Category classification if all models had been placed on the market after publication and mandatory application of [1]. In fact, they currently correspond to class C5, which is to be labelled, but is not subject to any noise limit value. This is also true for C3.

All models were measured 0.5 m (centre of the UA) above the reflective surface in the hover condition. The definition of the flight altitude for noise measurements of UAs was removed after the amendment of reference [1] by Delegated Regulation 2020/1058 [4]. However, it is still included in DIN EN 4709-001:2021-02 [5]. This draft standard provides technical specifications and test methods to support compliance with [1]. The measurements were repeated at least 5 times for each UA model, while the measurement duration was 5-10 seconds.

3 Measurement Results

All measurement results were provided with the correction parameters K_1 (background noise correction) and K_2 (environmental correction) according to [3]. Besides that, A-weighting was added to the sound level.

Table 2 shows the results of the surface time-averaged sound pressure level ($\overline{L_P}$) according to the following equation (1):

$$\overline{L_P} = \overline{L'_P(ST)} - K_1 - K_2 + A \qquad (1)$$

with

$\overline{L'_p(ST)}$ the mean value formed over all microphone positions on the measurement surface, while the noise source under investigation is in operation.

K_1 background noise correction parameter determined according to [3] section 8.2.3

K_2 environmental correction parameter, here $K_2 = 0$, since according to [3] section 4.3.1 K_2 can be neglected for outdoor measurements with a reflecting plane of asphalt or concrete.

A A-weighting

According to reference [1], *"the A-weighted surface time-averaged sound pressure level [$\overline{L_p}$] shall be determined at least three times for each UA configuration. If at least two of the determined values do not differ by more than 1 dB, further measurements will not be necessary; otherwise the measurements shall be continued until two values differing by no more than 1 dB are obtained. The surface time-averaged sound pressure level*

[$\overline{L_{px}}$] to be used for calculating the sound power level of a UA configuration is the arithmetic mean of the two highest values that do not differ by more than 1 dB."

To comply with the requirements, the values that satisfy the 1 dB criterion and the number of measurements were selected from the measurement results. The values used to determine the arithmetic mean are highlighted with blue background colour in Table 2. In Table 2, "x" denotes inadequate measurements, which were consequently excluded from the validation. This is owed to the fact of sudden gusts of wind, too much background noise or undesired position corrections.

Table 2: Results of the individual measurements and the surface time-averaged sound pressure level.

	UA 1	**UA 2**	**UA 3**	**UA 4**	**UA 5**	**UA 6**	**UA 7**	**UA 8**
measurement	$\overline{L_P}$ in dB(A)							
1	78.5	x	x	65.8	59.2	75.6	x	66.8
2	78.6	77.6	77.9	64.7	x	75.5	67.8	66.8
3	78.6	78.3	x	x	59.9	76.4	66.5	67.0
4	78.7	x	77.8	65.1	60.7	x	66.8	66.6
5	78.9	77.5	77.4	66.1	59.2	75.7	66.4	x
6	78.9	78.1	78.0	-	-	-	67.5	67.3
7	-	77.9	-	-	-	-	-	66.9
8	-	x	-	-	-	-	-	67.4
$\overline{L_{px}}$ in dB(A)	78.6	78.0	77.8	65.5	60.3	76.0	67.3	66.9

The sound power level was determined according to the following equation (2):

$$L_{WA} = \overline{L_{px}} + 10\, lg \frac{S}{S_0} dB \tag{2}$$

with

S area of the measurement surface, here area of a hemisphere with radius $r = 4$ m

S_0 $S_0 = 1\, m^2$

According to reference [1] Part 14, the guaranteed sound power level must be indicated in a pictogram on the product. The definition of the guaranteed sound power level in this regulation is given as follows:

"[…] *a sound power level determined in accordance with the requirements laid down in Part 13 of the Annex which includes the uncertainties due to production variation and measurement* […]*"* [1]

Thus, an expanded uncertainty U was determined according to paragraph 9 of reference [3] with equation (3) and (4):

$$U = k\sigma_{tot} \tag{3}$$

$$\sigma_{tot} = \sqrt{\sigma_{R0}^2 + \sigma_{omc}^2} \tag{4}$$

with

k coverage factor, here $k = 2$ because only one model per species was available and no further database is known.

σ_{tot} total standard deviation

σ_{R0} all uncertainties allowed by the measurement standard, except those for the instability of the sound power of the source under investigation (σ_{omc}). In this case 1.5 dB, since no value specific to the product is known or has been determined so far.

σ_{omc} standard deviation for determining variations in operating and installation conditions, determined, here over all valid measurements from Table 2.

The expanded uncertainty U was added to the calculated L_{WA} to obtain the guaranteed sound power level. The results are shown in Table 3.

Table 3: calculated vs. guaranteed vs. maximum sound power level

	UA 1	**UA 2**	**UA 3**	**UA 4**	**UA 5**	**UA 6**	**UA 7**	**UA 8**
calculated L_{WA} in dB (A)	98.6	98.0	97.8	85.5	80.3	96.0	87.3	86.9
U in dB	3	3.1	3	3.3	3.3	3	3.1	3.1
guaranteed L_{WA} in dB (A)*	102	101	101	89	84	99	90	90
max. L_{WA} in dB (A)				88.1	85.0		92.7	90.1

*According to [1] the guaranteed sound power level needs to be rounded to integer values.

Likewise, the theoretical maximum sound power level (max. L_{WA}) was determined according to [1] Part 15. For UA weighing more than 4 kg (classes C3, C5 and C6), unfortunately no values are given in the reference, so only the values of the "smaller/lighter" UA are apparent. For further details refer to sections 5 and 6.

4 Application Issues

The obtained results cannot be regarded as representative/absolutely conforming to standards, since some compromises or assumptions were made during the measurements and evaluation. The reason for this is that too little experience or no testing of the measurement method with UA is available so far and therefore a suitable database is missing.

According to [3], the measurement time should be 20 s, but must be at least 10 s. However, experience from the measurements carried out shows that a duration of 20 s is hardly possible. Even under optimal conditions, the UA drifts away from its initial hover position and corrections have to be made by the UA pilot to remain at this position. Likewise, the GPS signal is usually not accurate enough to maintain the required position (± 0.05 m) [5]. This could affect the measurement significantly. Therefore, for some UA models the measurement time had to be reduced to 5 s. However, this was seen as acceptable for the purpose of the measurements.

In case it is not possible to keep a stable position, the UA shall be mounted on a tripod or should be tethered to limit horizontal movements of the UA according to reference [5]. This is hardly possible for users who cannot intervene in the UA system, e.g. by setting specific rotor speeds. If mounted on a tripod, the UA would immediately apply full torque to the motors/rotors as it tries to lift off to get into hover position. The feedback controllers would try to compensate for the weight of the tripod. This, would distort the measurement results.

Another ambiguity was the specification of the hover position of 0.5 m above ground level. Before the amendment of [1], no further information was given as to where the 0.5 m was to be applied (UA center, rotor plane, foot plane). If the center or rotor plane was assumed, the problem arose, especially with UA over 4 kg and larger dimensions (cf. UA 1-3, Table 1), that they were only allowed to lift off a few centimeters above the ground. Thus, safe hovering was hardly possible. Due to changes in [1], the height requirement has been eliminated. However, this is included in the draft of the concretizing standard [5], where the foot plane is taken as the reference. It is questionable to what extent the resulting different heights of the rotor plane for different UA models will affect the measured values.

5 Evaluation Issues

For the evaluation the correction parameters K_1 and K_2 must be determined. K_1 is determined from the difference between the extraneous noise level and the product noise. Here the problem arises that especially for smaller UA the difference is insufficient. The reason for this is the given radius in [3] Annex F. This Annex was originally developed for the measurement of construction machines. The smallest option of $r = 4$ m is usually too far for UA below 4 kg and therefore causes an invalid K_1. Consequently, the UA noise differs too little from the extraneous noise.

The environmental correction parameter K_2 can be neglected in our case. According to [1] the determination of K_2 for measurements in space is left optional. Annex A of reference [3] gives various possibilities for determining the environmental noise correction.

To determine the uncertainties required for the guaranteed sound power level, a coverage factor k and further uncertainties must be specified. There is currently a great deal of leeway here, since the regulation does not specify any correction values. As far as the authors know, there is a lack of preliminary investigations to determine suitable values. The coverage factor k could be determined through a series of tests by the manufacturer. In each configuration, a certain number of the same model should be tested and indicated in the measurement report. Yet there is no obligation to do so. Section 9.1 of reference [3] indicates that a coverage factor of $k = 1.6$ dB would be more appropriate when comparing the sound power level to a limit value. However, since no data basis exists yet, this assumption is not worth supporting. The same applies to the uncertainty σ_{R0}. For this purpose, large-scale interlaboratory tests would have to be performed by different manufacturers, UA models, and measurement institutes to produce valid results.

Due to the missing clear specification of these two values, the manufacturer is free to correct the measured, guaranteed or maximum sound power levels in a desired direction.

Another discontinuity in [1] is that the term maximum sound power level is not specified. This raises two questions: Should the maximum permissible guaranteed sound power level or the maximum measured sound power level be specified here? Which sound power level should be included in the report?

Furthermore, it is not clear how the indicated maximum sound power level was determined or on what data basis it was based. The authors are not aware that there has been any analysis of existing products in this regard. The Outdoor Directive 2000/14/EC [2] was used as a model for parts 13-15 of reference [1]. However, the noise limits specified there are based on a variety of preliminary studies, the results of which form the basis for the setting [6, 7]. These studies were funded by the Commission for this reason.

6 Conclusions

Although the measured models comply with the defined noise limits (as far as possible), there are still some issues that must be clarified.

In general, it can be emphasized that there are still too few studies dealing with UA noise and its mitigation. The Delegated Regulation 2019/945 [1] can be regarded as a first step towards reducing the physical noise pollution caused by UA. However, it should be optimized in the sections mentioned in this paper and a database should be evaluated. Similarly, it is not yet sufficient to evaluate the extent of noise effects, such as annoyance. This is influenced by various acoustic and non-acoustic factors that need further investigation.

In most cases, the data from literature sources only refer to UA of the multicopter type. A broader data base and a standardized measurement practice that also includes other design configurations would be necessary. Furthermore, the emission model should distinguish different operating states: hovering, take-off, landing, climbing, descending and level flight with "typical" forward speed. In practice, different operating states have different noise characteristics that are not comparable with each other. Hovering is the quietest and most unrealistic condition and section 6.6 of ISO 3744:2010 specifies that the measured object shall be measured under conditions that are representative of the noisiest mode of operation under normal use.

Just as the development of UA is far from complete, the standardization framework as well as the legal framework must also be further developed, adapted and tested in order to create appropriate specifications for UA operation. Environmental protection and noise abatement (still) plays a subordinate role but should be given greater consideration in order to protect the public from an additional noise source.

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