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NOISE MEASUREMENTS FROM DRONES TO ESTIMATE FUTURE NOISE EXPOSURES

Julia Treichel
German Environment Agency, Dessau-Roßlau, Germany
email: julia.treichel@umweltbundesamt.de

Jan Foerster and Prof. Dr. Maarten Uijt de Haag
Technical University Berlin, Berlin, Germany

Temu Joonas Lieb and Andreas Volkert
German Aerospace Center, Braunschweig, Germany

Unmanned Aircraft Systems (UAS) are used for a variety of purposes. Especially the industrial or professional use of UAS will lead to an increasing number of possible applications. The steadily increasing number of drones raises the question of noise impact from these unmanned aircraft. Therefore, the German Environment Agency has started with acoustic investigations of drones. Various small UAS models (i.e. multicopter) were used in a measurements campaign. For example, overflights at different altitudes and speeds were measured. In addition, binaural measurements were performed to provide psychoacoustic findings.

In this paper the measurements and results are presented. Overflight levels are compared with psychoacoustic quantities such as loudness or sharpness. Likewise, conclusions are drawn for the evaluation of drone noise, which can be used for future regulations or standardization.

Keywords: drone, noise, UAS, measurement

1. Introduction

Current developments in the field of UAS and the associated legislation show that UAS will be used increasingly in the future, not least because longer flight times and greater payloads are possible. At present, the application is mainly in the service sector, such as maintenance tasks or the transportation of medical goods, as well as in the crises management, e.g. for rescue operations. With the introduction of the so-called U-Spaces in urban areas [1], airspaces specifically for UAS use, further fields of application will be opened up.

The resulting increase in the number of UAS [2] raises the question of future noise pollution and annoyance. There are currently no well-founded findings on these issues either nationally or internationally. UAS have their own new noise characteristics that are added to road, rail and conventional aircraft noise in urban areas. It is, therefore, foreseeable that more and more people will feel disturbed by the noise of UAS flights in the future or are at least concerned about the expected noise annoyance [3].

To get an impression of the noise characteristics of drones, various drone models were recorded by means of overflight measurements and some acoustic properties were investigated. Since there is no established noise measurement method for drones, this paper considered various metrics that could be used in the future. The results are presented below.

2. Measurement setup

So far, there is no standardised or legally defined measurement procedure to determine the noise characteristics or emission/immission levels of UAS. Only the Delegated Regulation (EU) 2019/945 [4] has included a noise measurement procedure to label UAS similar to the Outdoor Directive [5]. This means that the guaranteed sound power level must be displayed on the device or packaging. However, this measurement method is not suitable for recording the real emissions of drones [6].

For this purpose, overflight measurements were carried out with eight different UAS models whose characteristics are given in Tab. 1.

Table 1: Specification of the used UAS models

	UAS 1	**UAS 2**	**UAS 3**	**UAS 4**	**UAS 5**	**UAS 6**	**UAS 7**	**UAS 8**
weight in g	500	900	1250	1320	2355	6200	7000	10000
size in cm	33 x 38 x 6	32 x 24 x 8	33 x 33 x 13	39 x 39 x 24	89 x 89 x 22	125 x 125 x 58	119 x 119 x 78	170 x 170 x 80
construction type	Quadro-copter	Quadro-coter	Quadro-copter	Quadro-copter	Quadro-copter	Octo-copter	Octo-copter	Octo-copter

The measurements took place outdoors at airfields in Dessau and Cochstedt over an asphalt runway (Fig. 1). The rest of the measurement environment was a spacious lawn without trees or buildings. Further reflections could therefore be excluded.

Figure 1: left: Setup on the airfield of the model flying club "Hugo Junkers" Dessau-Rodleben/Germany

right: Setup at the National Experimental Test Center for UAS (DLR) in Cochstedt/Germany

The measuring points were at a height of 1.2 m above the ground. This height was taken because it is common in the previous national measurement procedures for aircraft noise [7]. The overflight took place at a height of 10 metres. Thus, the distance from measuring position to reference point was 8.8 m. The reference point in this case was the centre of the connecting line of the propeller hubs furthest out. Further microphones were placed to the right and left at a distance of 7.5 m from the centre microphone position [8] as shown in Fig. 2. The models were measured at a speed of 5 m/s and 10 m/s, respectively.

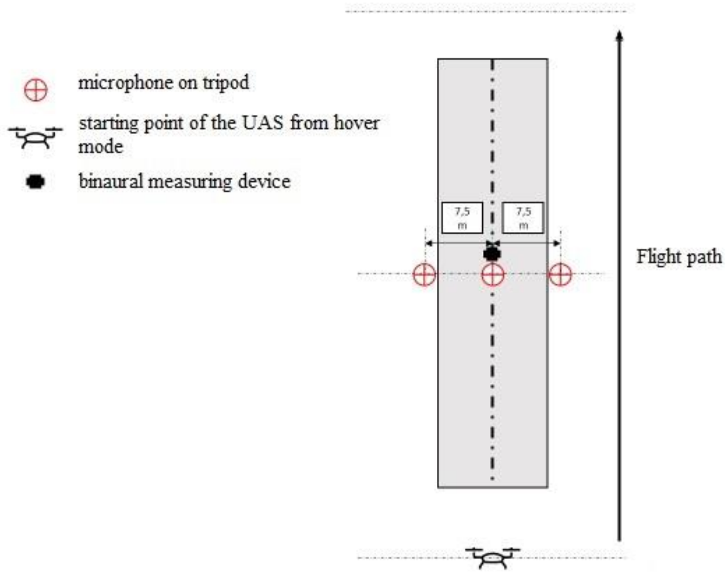

Figure 2: measurement setup with microphones and UAS

A major challenge during the measurements was controlling the UAS to fly at an exact overflight height, centred above the middle microphone. Many measurements had to be repeated because the UAS deviated from its course during the approach or overflight. Manoeuvring in the approach area or in the measurement plane causes acceleration of the UAS an, thus, the speed to change. This has an effect on the noise development. In our case, we kept the deviations low in the evaluation by placing the microphones to the side and using an additional binaural measurement system.

3. Measurement results

Due to the newness of the noise source and the lack of experience, various acoustic and psychoacoustic properties were evaluated. The considered metrics could be useful for the development of an assessment procedure for UAS noise.

3.1 Overflight and maximum sound pressure level

In order to be able to better compare the results of the various overflights and UAS models, the time of the overflights was trimmed in the evaluation. For this purpose, the maximum sound pressure level (SPL) of the overflight was determined as well as the time stamp at which the UAS was exactly above the microphone. Afterwards, 5 s before and 5 s after the overflight's maximum SPL were extracted from the data time serie. This 10 s signal was included in the evaluation. In addition, the overflights were repeated at least 10 times. From these 10 measurements, 4 valid measurements were taken and averaged for evaluation. Invalid measurements can occur if sudden gusts of wind or excessive background noise occurred during the flight, and if the UAS deviated too much from the actual flight path.

Tab. 2 and Tab. 3 show the average maximum SPL determined for each UAS examined at different speeds by means of overflight.

The single SPL L_{pASmax} was selected as the evaluation parameter here because it is also an important criterion for recording the noise event in conventional aircraft noise assessment [7,9]. As mentioned above, there is no regulated measurement method for UAS. Therefore, it is not conclusively clarified whether the UAS noise should be evaluated with the time rating SLOW or FAST. Therefore, the evaluation was repeated in FAST mode for comparison.

Table 2: slow weighted maximum SPL

	UAS 1	UAS 2	UAS 3	UAS 4	UAS 5	UAS 6	UAS 7	UAS 8
	L_{pASmax} in dB(A)							
***v* = 5 m/s**	60.8	62.4	59.7	60.1	65.3	72.0	n.a.	72.3
***v* = 10 m/s**	59.9	64.3	59.5	57.8	60.9	71.0	75.5	70.5

Table 3: fast weighted maximum SPL

	UAS 1	UAS 2	UAS 3	UAS 4	UAS 5	UAS 6	UAS 7	UAS 8
	L_{pAFmax} in dB(A)							
***v* = 5 m/s**	63.2	63.4	60.3	62.0	66.7	73.1	n.a.	73.7
***v* = 10 m/s**	61.9	66.7	61.6	59.9	63.3	72.4	77.4	72.5

In conventional aviation, the L_{pAmax} is included in the calculation of the noise assessment level [10]. Should this also be a future evaluation criterion for UAS noise, the choice of the time-based evaluation method plays a major role; here the differences vary between 1-3 dB.

In addition, there is a tendency for the UAS to have a lower maximum level at higher speeds.

For a better overview, the averaged overflight SPL for the two measured speeds are shown in Fig. 3 and Fig. 4 using the SLOW evaluation mode. Also, here it can be seen that the higher speed results in lower levels. Furthermore, a clear level difference of approx. 10 dB is evident between the UAS < 4 kg and > 4 kg.

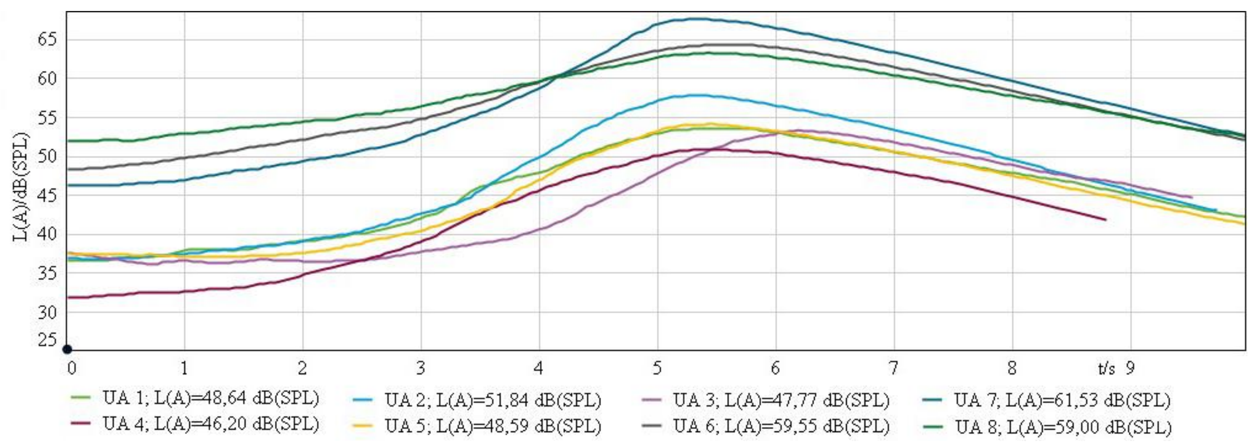

Figure 3: overflight SPL with *v* = 10 m/s

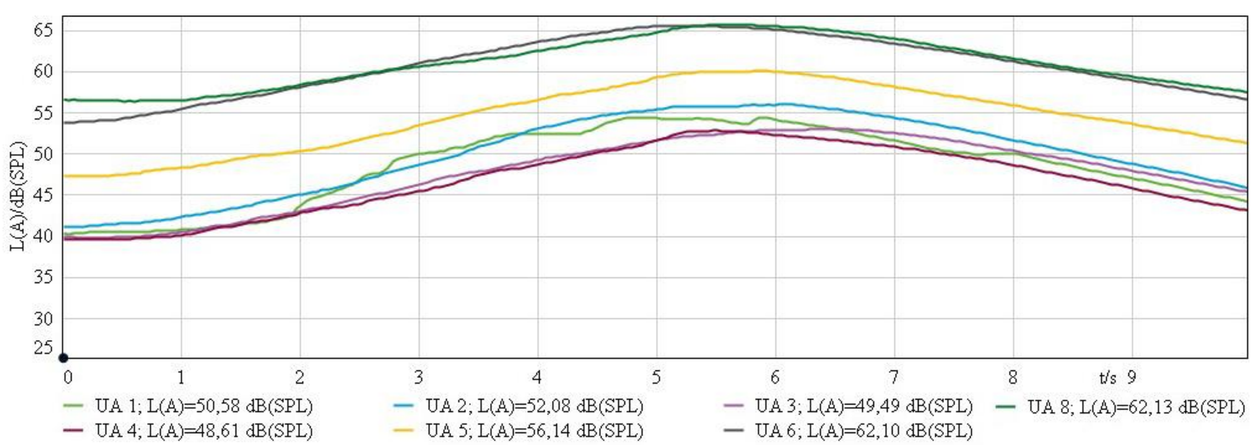

Figure 4: overflight SPL with *v* = 5 m/s

3.2 Spectral analysis

To get detailed information about the complexity of a sound signal, more information about the frequency composition of the signal must be determined. This can be done by performing a FFT or third-octave spectrum analysis. Fig. 5 shows the A-weighted third-octave spectra of the tested UAS models with v = 10 m/s.

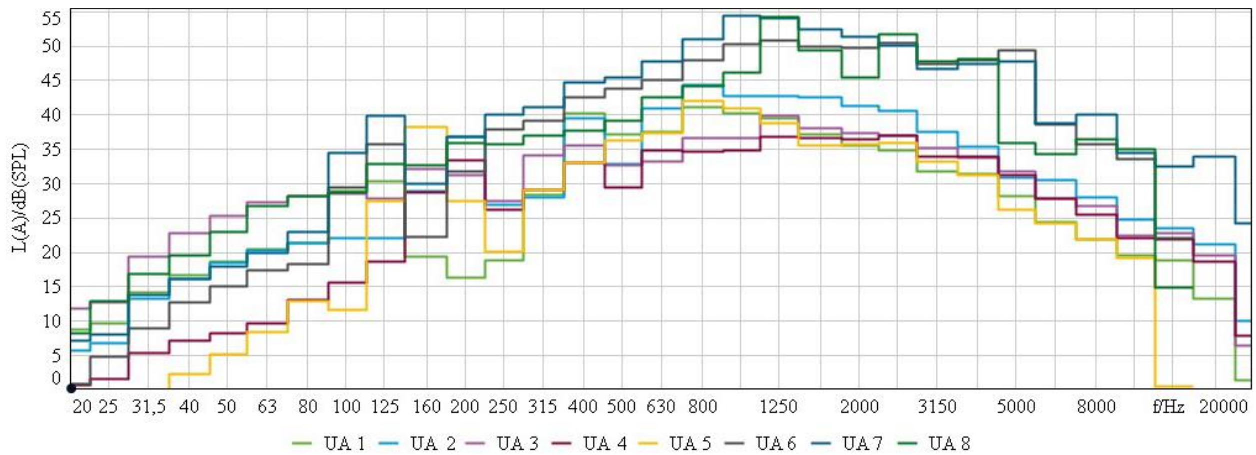

Figure 5 third-octave spectrum analysis with v = 10 m/s

It can be seen that the UAS noise is mainly determined by the range 0.5 kHz to 5 kHz by a broadband noise. In the range between 100 Hz and 200 Hz, there is typically a peak in the spectrum. If you look at the FFT analysis (Fig. 6), you can see further peaks up to 1 kHz. It can be assumed that this is the fundamental frequency of the electric motor and its harmonics.

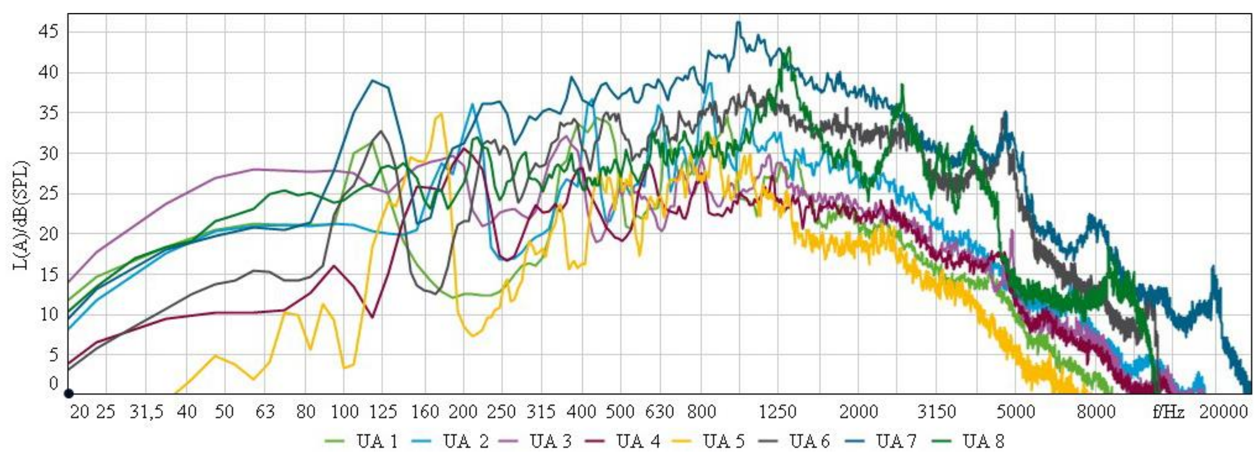

Figure 6: FFT analysis with v = 10 m/s

3.3 Psychoacoustic analysis

According to a psychoacoustic study conducted by NASA in 2017 [11], UAS sounds are more disturbing than car sounds. For this study, test subjects were played recordings of UAS at different flight altitudes and speeds. The subjects were not informed that these were UAS sounds.

Psychoacoustic quantities can help to better describe the actually perceived auditory impression and should be considered in addition to the pure physical quantity SPL [12].

In addition to the SPL, the psychoacoustic parameters loudness and sharpness were recorded by a binaural measurement system during the overflight measurements. The measurement setup did not differ from the measurement described in the previous chapter.

3.3.1 Sharpness

The sharpness [13] is an indicator of the distribution of high and low frequencies in a sound. The sound is perceived sharper if more high frequencies are contained. The results for sharpness are summarised in Fig. 7 and Fig. 8 for both UAS speeds.

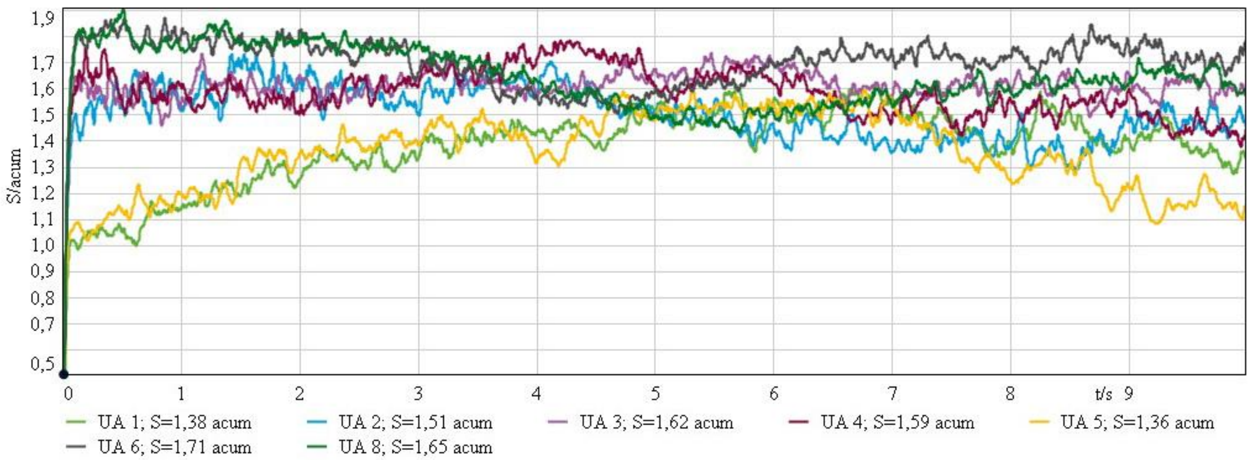

Figure 7: sharpness with v = 5 m/s

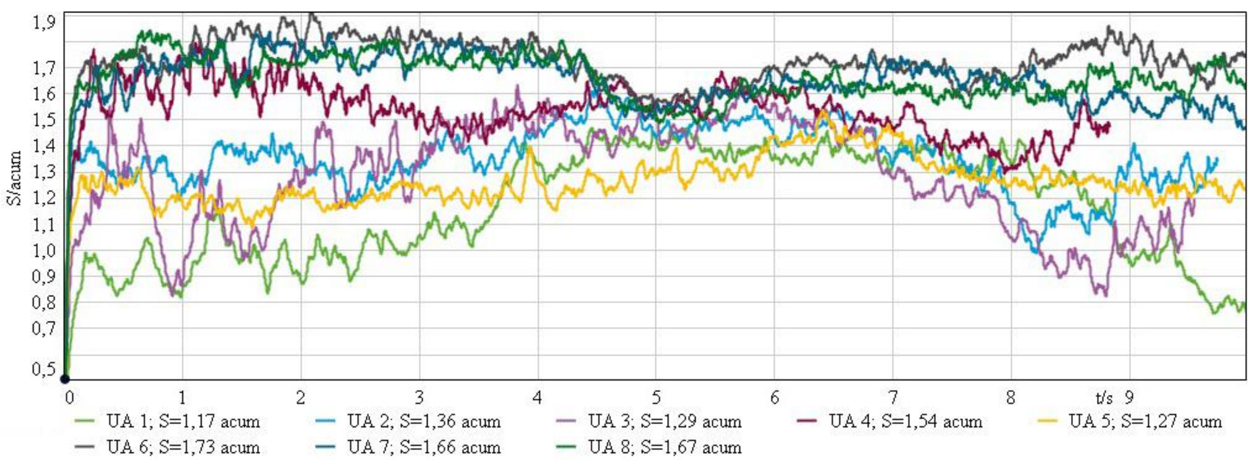

Figure 8: sharpness with v = 10 m/s

It can be said that the sharpness various strongly between the UAS. This is particularly evident for a speed of v = 10 m/s. At the moment of the overflight, the sharpness curves come together and then diverge again. The UAS with masses larger than 4 kg are more or less on the same level and also show the highest sharpness values. There is a slight tendency for the UAS noise to be perceived as less sharp at higher speeds. Nevertheless, the curves here have higher levels of fluctuating.

3.3.2 Loudness

Loudness depends on the signal's spectral distribution. It takes into account the level-dependent loudness perception for different sounds and the duration as well as simultaneous and post-masking properties of the human auditory system [14]. Thus, it reflects the perceived loudness better than a pure SPL.

As expected, the loudness increases up to the moment of overflight where it reaches its maximum and then levels off again. Also, here, it can be seen that the models > 4 kg are perceived louder than the other models (see Fig. 9). In addition, a strong concentration of both the lighter models and the heavier models can be observed. The spread between the lowest and highest loudness is considerable. From the SPL and loudness time curve it can be seen that when a drone approaches, the moment of loudest perception is shortly, circa 0.5 s, before the actual level peak. This is shown in Tab. 4 for three exemplary UAS models. We perceive the UAS as more disturbing when flying over us shortly before than directly above us.

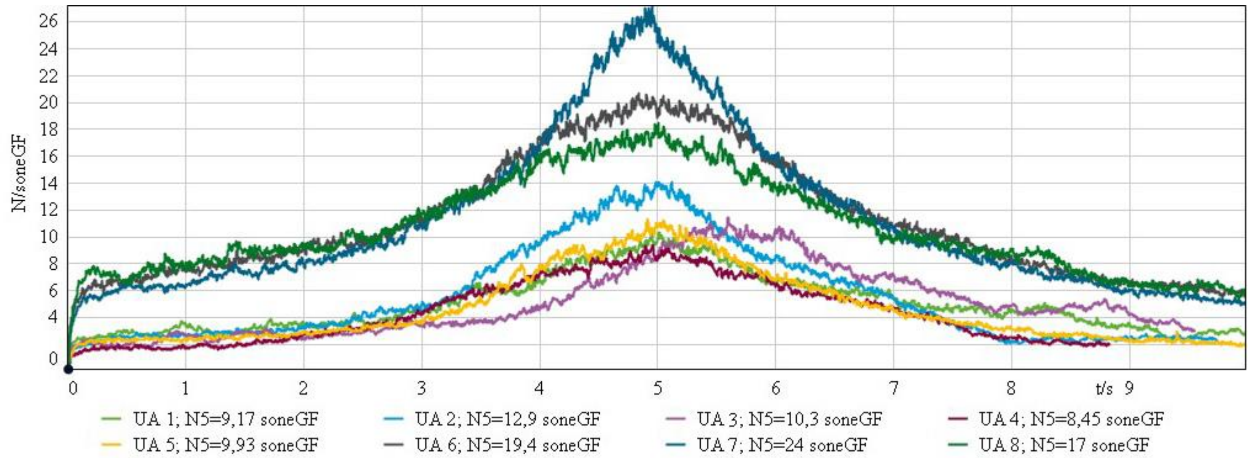

Figure 9: loudness with v = 10 m/s

Table 4: Comparison of SPL time curve and loudness time curve with v = 10 m/s

	UAS 1	**UAS 5**	**UAS 8**
	timestamp at max. value in s		
SPL	5.46	5.42	5.42
loudness	5.01	4.91	5.00

When considering the specific loudness, meaning the distribution of the loudness over the different frequencies, a peak can be seen in the range between 100 – 200 Hz. This can again be attributed to the primary frequency of the electric motor. In addition, UAS > 4 kg are also perceived as being considerably louder especially in the high frequencies.

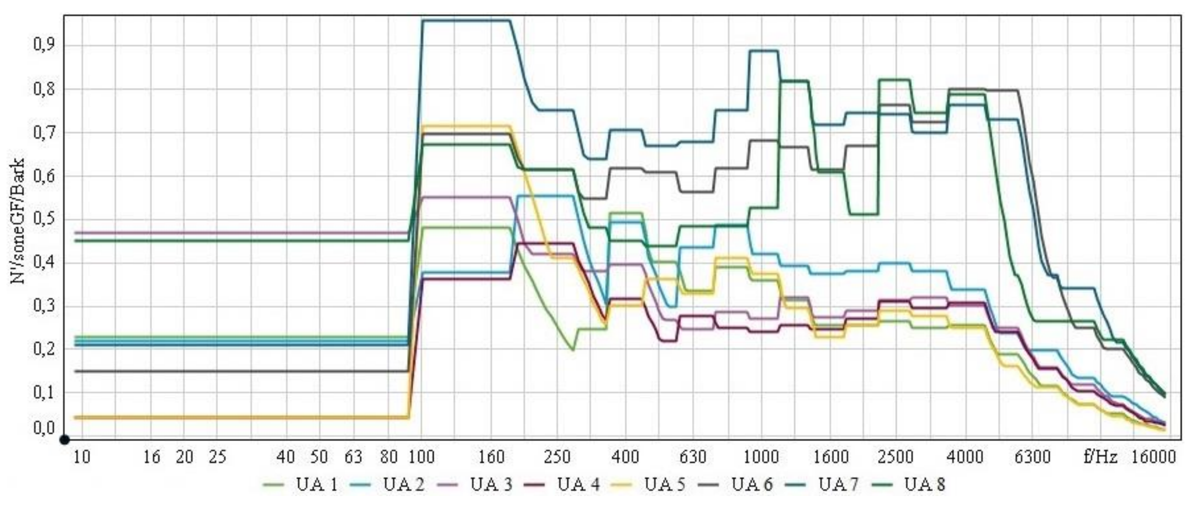

Figure 10: specific loudness with v = 10 m/s

4. Conclusion

As the measurement results show, UAS are not necessarily loud in the sense of generating high sound levels. However, the maximum noise levels measured during a straight overflight without steering vary by up to 18 dB between the UAS models considered. Basically, it can be said that UAS can be perceived as disturbing due to their sound's frequency composition. The analyses carried out show that the models over 4 kg always show the maxima. However, due to their payload, these UAS are the ones that will be used for transport in the future or are already being used for inspection purposes. As a new source of noise, UAS have not been sufficiently investigated, especially their psychoacoustic annoyance. A research project by the German Environment Agency is providing initial findings in this regard [15]. Various measures are conceivable in the future to reduce the environmental impact of UAS operations. First of all, a standardised measurement procedure should be developed that can map all operating states of the UAS. Especially the sudden manoeuvres can cause short-lived noise pollution, which increases the disturbance factor. These disturbance factors, as well as the psychoacoustic aspects, should be mapped in a regulatory noise assessment procedure as an allowance. The existing operational restrictions, such as the limited use of UAS in residential areas, currently protect people from exposure to drone noise. With the implementation of U-Spaces in urban areas, it remains to be seen where the development will go. Until now there is no specification or idea how to evaluate the expected over all noise levels during the opening time of these U-Spaces.

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