Determination of Sound Power Levels of a Small UAS during Flight Operations

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ABSTRACT

Unmanned Aircraft Systems (UASs), also called Unmanned Aerial Vehicles (UAVs), have mostly found military applications, but also are increasingly finding uses in civil applications, such as search and rescue operations, 3D mapping, environments monitoring, industrial applications (inspection of power plants or pipelines), TV Entertainment. The UASs are often preferred for missions that are very difficult or dangerous for manned aircraft or for men in general. The use, in everyday life, of this type of vehicles further increase the total acoustic pollution. It is necessary to evaluate the Small UAS noise, in manner to determine its contribution to total acoustic pollution. Goal of this work is to evaluate the acoustic emissions of some small UASs during normal flight operations (e.g. take off, landing, turning, hovering, etc.), related to electric engines and propellers. The acoustic measurements are carried out in an anechoic room. Data collection of small UASs noise, at low altitude and velocity, were made. Investigation on sound power levels is based on EN ISO 3745, which specifies measurement method. The results of each UAS have been presented and discussed.

Keywords: UAS, Acoustic, Flight Mechanics, Noise, Environmental Impact.

1. INTRODUCTION

Unmanned Aircraft System (UAS) play an important role in various military and civil applications, especially for monitoring and surveillance of areas (urban traffic, coast guard patrol, border patrol, detection of illegal imports, archeological site prospection, etc.), climate research (weather forecast, river flow, etc.), agricultural studies, air composition and pollution studies, inspection of electrical power lines, monitoring gas or oil pipe lines, entertainment and TV, etc.

Currently, a broad range of UASs exists, from small and lightweight fixed-wing aircrafts to rotor helicopters, large-wingspan airplanes and quadrotors, each one for a specific task, generally providing persistence beyond the capabilities of manned vehicles [1,2]. According to Table I [3], UASs can be categorized with respect to mass, range, flight altitude and endurance.

Table 1 - Extract of UAS/UAV cat. Defined by UVS (Unmanned Vehicle Systems Association)

<table>
<thead>
<tr>
<th>Category Name</th>
<th>Mass [kg]</th>
<th>Range [km]</th>
<th>Flight Altitude [m]</th>
<th>Endurance [hours]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro</td>
<td>&lt;5</td>
<td>&lt;10</td>
<td>250</td>
<td>1</td>
</tr>
<tr>
<td>Mini</td>
<td>&lt;25/30/150</td>
<td>&lt;10</td>
<td>150/250/300</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Close Range</td>
<td>25-250</td>
<td>10-30</td>
<td>3000</td>
<td>2-4</td>
</tr>
<tr>
<td>Medium Range</td>
<td>50-250</td>
<td>30-70</td>
<td>3000</td>
<td>3-6</td>
</tr>
<tr>
<td>High Alt. Long Range</td>
<td>&gt;250</td>
<td>&gt;70</td>
<td>&gt;3000</td>
<td>&gt;6</td>
</tr>
</tbody>
</table>

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For this paper, a small quad-rotor is chosen. This type of UAS has a good ranking among VTOL (Vertical Take-Off and Landing) vehicles, yet it has some drawbacks. For example, the craft size is comparatively larger, energy consumption is greater, therefore providing short flight time, and the control algorithms are very complicated, due to the fact that only four actuators are used to control all six degrees of freedom (DOF) of the craft, and that the changing aerodynamic interference patterns between the rotors have to be taken into account [1, Chap. 3], [4, Parts I and II]. The noise, in the same way, will be proportional to vehicle size and so with its power-source; in particular, it is mainly created by two sources: (a) propulsion system (i.e. electric engine, internal combustion engine, etc.), (b) aerodynamic noise.

Aerodynamic noise of aircrafts, in general, is mainly made from vortices at the tips of wings, rotors or propellers and airflow around the control and aircraft fuselage surfaces. This increases with wing or blade span loading and speed, so that low values both enhance acoustic stealth [1]. Noise generally increases with power-source usage level, so that keeping the mass and aerodynamic drag of the vehicle as low as possible is a good first step to achieving low noise generation.

Aim of this paper is to evaluate the acoustic emissions of some small UAVs, discussed in detail in next section, during normal flight operations (e.g. take off, landing, turning, hovering, etc.), related to electric engines power level and propellers spin velocity. The acoustic measurements are carried out in an anechoic room through a certified phonometer. Data collection of small UAVs noise, at low altitude, low velocity, and in a fixed position were made. Investigation on sound power level (SPL) is based on Standard EN ISO 3745, which specifies measurement method. The results of each UAV considered, have been presented and discussed.

The paper is structured as follow:

1. Introduction;
2. UAV Systems;
3. Instrumentation;
4. Noise Measurements;
5. Results;
6. Conclusions.

2. UAS Systems

In this work, two different models of small quad-copters were analyzed. In particular, they are:

a. Syma X5C;
b. RC Eye One Xtreme.

The technical characteristics and performance will be explained in detail in next sections. It is important to consider that this small UAS have been chosen for their robustness, lightweight, low-cost and fast response time properties.

2.1 Syma X5C

The Syma X5C (Figure 1) comes with a 6-Axis Gyroscope which allows for strong balance in the air and precise hovering, even when there is a light wind due to four-axis structure [5]. For beginner, there is a 360 Degree Eversion control that allows the X5C to roll continuously in flight without sacrificing control. The Spread Spectrum Control (SSC) allows for greater flight distance, responsiveness, and duration with less interference than radio control. Thrust is generated due to four DC (direct current) motors. In addition to flight control, the Syma X5C comes with a 2MP 720P HD Camera for taking fantastic pictures and videos from the air. If flying at night is your thing, the Syma X5C also comes with green and orange lights that helps you spot it at night and keeps you oriented. However, in this work, UAV is fixed on a tripod and so camera and lighting is not necessary, in order to have much more battery endurance they were disabled.
This UAS is not a toy, but in everyday life, main users are child; thus, it is important to consider its influence on environment, through noise power emission evaluation. This product is chosen for its low cost, solid structure, spare parts easy reachable and fast time of response.

2.2 RC Eye One Xtreme

Another UAS, used for this research, is RC Eye One Xtreme (Figure 2), a micro-quad-rotor; it is one vehicle of a new series [6]. In this case, the UAS is smaller than X5C, but better in terms of performance. Micro-quad will be the future of UAS technologies.

Latest 6-axis gyro stabilization technology, outstanding brushless motor (better than X5C DC motors) driven flight control, all embedded within a robust yet stylish frame design. The sturdy lightweight construction is an ideal platform for flight applications ranging from aerial surveillance, imaging or simply unleashing acrobatic fun flight excitement. It is possible to select two flight modes: beginners and experts flight enjoyment alike. In this work, for data session, beginner’s mode is enabled.

A 2.4 GHz receiver equips quad-rotor, therefore it is possible to configure a 2.4 GHz transmitter, in order to control and manage it. As X5C, also RC Eye One Xtreme on a tripod during data collection is fixed.

Both UASs use different colors (e.g. for propellers, led, legs, etc.) to distinguish the nose from the tail, this is important for the referencing during data collection. Each point acquired, need to be referenced respect a reference coordinate system. Both UAS data collection and measurements was
evaluated in a reference system, where its origin is the centroid of the vehicle.

3. Instrumentation

The data collection, useful to acquire sound power level (SWL) of the UAVs, was made due to a classical instrumentation, listed below:

- Anechoic room;
- Sound Level Meter;
- Tripod.

This is the minimum instrumentation required [8] to have a good data collection experience. Next paragraphs will explain in details the instrumentation features.

3.1 Anechoic Room

The chamber (Figure 3) consist of an inner room (4.40 m x 4.40 m x 4.50 m) covered by absorptive fiberglass wedges providing a very quiet environment and outer shell of reinforced concrete. It is a room ideally very free acoustic reverberation at any frequency and fully absorbent. The cut-off frequency of the chamber is 100 Hz.

![Anechoic room](image1)

Figure 3 - Anechoic room, situated in Built Environment Lab Ri.A.S. (Ricerca Applicata e Servizi – Applied Research and Services).

3.2 Sound level meter

Measurements were carried out using a sound level meter 01dB type Solo SLM (Figure 4), a precision data-logging sound meter level. Overall technical specifications in Table 3 has been reported [7]. The equipment was calibrated by means of the 01-Metravib acoustic calibrator “CAL21” (Figure 4).
The SOLO sound level meter is a class 1 multipurpose metrological instrument that is suitable for the measurement environmental noise. During the experiments were measured equivalent continuous levels $L_{eq}$, pressure levels $L_p$, with A frequency weight ($(dB(A))$ and Lin (dB). It can also record 1/3 octave spectral frequencies. Data are stored in the non-volatile memory and then uploaded for reading in the dBTRAIT software.

3.3 Tripod and holding systems

For a good acquisition, it is necessary to have a fixed system (source-receiver), that reduce the error of positioning between the source and the receiver. The vehicle need to be fixed in a point, because during motion, the propellers can induce vibrations on whole structure. This effect leads an additive noise that has not to be included in the analysis.

For this work, two tripods and a simple holding structure was made. The tripods (Figure 5) was utilized for phonometer and UAS standing, instead a holding structure, composed by a simple hood rod useful for UAS fixing.

4. Noise Measurements

Acoustics determination of sound power levels (SWL) of noise sources using sound pressure precision methods for anechoic and hemi-anechoic rooms, due to UNI EN ISO 3745 [8] has been carried out. When the microphone positions are associated with equal partial areas of the test sphere (or hemisphere), the following equation shall be used to obtain the surface sound pressure level (SPL), $L_{pf}$:

$$L_{pf} = 10 \lg \left( \frac{1}{N} \sum_{i=1}^{N} 10^{0.1 L_{pi}} \right) dB$$

(1)

Where $L_{pf}$ is the surface sound pressure level over the test sphere, in decibels (ref. 20 µPa), $L_{pi}$ is the sound pressure level corrected for background noise resulting from the i-th microphone position, in decibels (ref. 20 µPa) and N is the number of microphone positions.

The sound power level (SWL) is calculated based on the Equation (2) where $C_1$ and $C_2$ are correction factors for room temperature and pressure. It should be noted that all values reported are A-weighted [8]:

$$L_w = L_{pf} + 10 \lg \left( \frac{S}{S_0} \right) dB + C_1 + C_2$$

(2)
Where $S_1$ is the area of the test sphere $(4\pi r^2)$ and $S_0=1m^2$ and $C_1$ and $C_2$ are:

$$C_1 = -10\lg \left[ \frac{B}{B_0} \left( \frac{313.15}{273.15 + \theta} \right) \right] dB \hspace{1cm} (3)$$

$$C_2 = -15\lg \left[ \frac{B}{B_0} \left( \frac{296.15}{273.15 + \theta} \right) \right] dB \hspace{1cm} (4)$$

$B_0$ and $B$ are respectively the reference barometric pressure (101325 Pa) and the barometric pressure during the measurements (Pa). The air temperature $\theta$ considered during acquisitions is degrees Celsius and it is important to specify that Eq. (2) is applicable in the temperature range $15^\circ C \leq \theta \leq 30^\circ C$.

4.1 Test bed

For each UAS data collection, has been considered different phonometer positions, with an uniform distribution along a sphere with a diameter of 1.2 meters. Figures 6 and 7 show the scheme of acquisition points (e.g. phonometer placement), for the Syma X5C and the RC One Eye Xtreme.

![Figure 6. Scheme of the sound level meter positions for Syma X5C.](image_url)
Sound power level in dB (linear) and dB(A), in the next paragraph, was calculated and compared. Figure 8 shows the UASs in the anechoic room with the instrumentation utilized for the data collections.

Figure 7. Scheme of the sound level meter positions for RC Eye Xtreme.

Figure 8 – a) Syma X5C and b) RC ONE Eye with the instrumentation in the anechoic room.
5. Results

The noise measurements are herein shown and discussed, respectively for RC Eye Xtreme and Syma X5C, considering different power level of the engines in ascending order, reported in Table 2. The power levels of the four engines are express in percentage of the full power of the UASs (full-throttle).

| Table 2 – Engine power levels considered during acquisitions. |
|---------------------------------|--------------------|
| **UAS**                         | **Engine power level [% full throttle]** |
| Syma X5C                        | 25 – 50 – 75 – 100 |
| RC ONE Eye Xtreme               | 25 – 65 – 100      |

According to [8], Table 2 show the sound power values in dB(linear) and dB(A), considering four power levels of the RC Eye Xtreme. Each condition has made, considering a time acquisition of 60 seconds for the Syma and 30 seconds for the RC ONE. The duration mainly depends on the stability of power absorbed by the engines. These conditions reproduce, in terms of flight maneuver, a hovering flight condition.

Table 3 shows that if the engine power increasing, the level of sound power emitted increase. Successively, the SWL (sound power level) per ⅓ octave band, respectively for conditions 1, 2, 3 and 4 (engine power levels – ref. Table 4).

| Table 3 – Sound Power Level for Syma X5C. |
|---------------------------------|----------------|
| **Condition**                  | **dB** | **dB(A)** |
| No. [% full throttle]          |       |           |
| 1                               | 10    | 86.6      |
| 2                               | 25    | 86.9      |
| 3                               | 50    | 86.9      |
| 4                               | 100   | 86.7      |
The graphs, in Figures 11A, 11B, 11C and 11D, show the values of sound pressure level (SPL) in which the maximum sound emission is in a range of frequency from 2 kHz to 8 kHz with a maximum at 4 kHz, while at low frequencies, the SPL is not significant except for the frequencies in ⅓ octave band about 125 Hz.

Figure 11 - SPL ⅓ octave band: A) Condition 1, B) Condition 2, C) Condition 3 and D) Condition 4.

As done for the Syma X5C, Table 3 shows the SWL in dB and dB(A) extracted during the data collection, considering the three conditions (Table 4) for RC One Eye Xtreme. The results for this UAS are similar to the first one, also in this case if the engine power increasing, the level of sound power emitted increase.

Table 4 - Sound Power Level for RC ONE Eye Xtreme.

<table>
<thead>
<tr>
<th>Condition</th>
<th>dB</th>
<th>dB(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>[% full throttle]</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>25</td>
<td>72.0</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>75.8</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>79.2</td>
</tr>
</tbody>
</table>

For RC One, the graphs, in Figures 12A, 12B and 12C, show the values of sound pressure level (SPL), the graph for the first condition shows that the maximum sound emission exists in a range of frequencies from 630 Hz to 2 kHz with a maximum at 1 kHz, while at low frequencies, the SPL is not significant. Instead, for the conditions second and third the maximum of sound emission is included in a range of frequencies from 315 Hz to 8 kHz, also in this case the SPL at low frequencies is not significant, except at frequencies around 125 Hz.

For further information, the directivity in the bottom plane has been studied. Figure 13 shows at the frequency 1/3 oct of 1.0 kHz the SWL directivity values, while Figure 14 show the SWL directivity at the frequency 1/3 oct of 2.0 kHz, for the three conditions considered.
Figure 12 – SPL ⅓ octave band: A) Condition 1, B) Condition 2, and C) Condition 3.

Figure 13 – SWL directivity values, at the frequency 1/3 oct of 1.0 kHz, for the three conditions considered.
6. CONCLUSIONS

In this work the extraction of the SWLs of small UASs were been evaluated and reported, in accordance with the standard UNI EN ISO 3745. This data will be useful in further work for noise impact in outdoor or indoor environments, in manner to estimate if its, during flight operations, cause a disturbance for people.

REFERENCES

8. UNI EN ISO 3745. Acoustics Determination of sound power levels of noise sources using sound pressure Precision methods for anechoic and hemi-anechoic rooms.