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Modelling sound radiation of rotorcraft small unmanned aerial vehicle for typical take-off and landing operations

This paper describes modelling of sound propagation from unmanned aerial vehicles in steady atmospheric conditions. Modelling includes influence of UAV operation mode on different flight stages and meteorological conditions. Different noise metrics is proposed for typical take-off and landing flight profile.

It is assumed that the operation of unmanned aerial vehicles (UAV) will occur in the urban area at altitudes of less than 150 m (fig. 1). In general, prediction of sound pressure level (SPrL) $L_p(r,\theta,f)$ of UAV is based on the sound power levels $L_w(f)$ of source in one-third octave/octave frequency band f according to the next equation:

$$L_p(r,\theta,f) = L_w(f) - 20\lg r - \Delta L(r,\theta,f) - 11,$$

where $L_w(f)$ is the result of experimental research [1], $\Delta L(r,\theta,f)$ is attenuation, which can be expressed as the sum of independent terms:

$$\Delta L(r,\theta,f) = \Delta L_{dir}(\theta) + \Delta L_{abs} + \Delta L_{imp} + \Delta L_{meteo} + \Delta L_{ground},$$

where $\Delta L_{dir}(\theta)$ is directivity factor, θ is directivity angle, ΔL_{abs} is influence of atmospheric absorption, ΔL_{imp} determines the effect of changing the impedance of the environment, ΔL_{meteo} takes into account additional attenuation in the atmosphere due to fog, precipitation and other adverse weather conditions, ΔL_{ground} is influence of terrain effects (type of surface, vegetation, buildings, facilities).

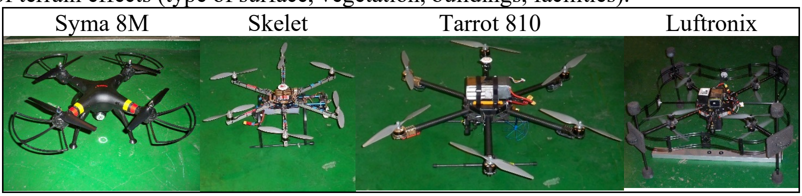

Fig.1. Photos of small rotorcraft UAVs tested in National Aviation University

Researches of the noise, produced by UAV, were carried out by means of modeling of take-off and landing flight condition. Various noise metrics is used to assess the reaction of the urban population to UAV noise: maximum A-weighted noise level L_{Amax} (dBA), A-weighted sound energy, normalized to a duration of 1 second, sound exposure level SEL_A (dBA), C-weighted sound energy with C-frequency correction, sound exposure level SEL_C (dBC), A-weighted equivalent continuous SPrL L_{Aeq} (dBA). Figs. 2 – 5 show dependence of noise metrics on distance in ground level horizontal plane from landing pad to sUAV for typical take-off and landing modes of rotorcraft UAVs (L_{Amax}, L_{Aeq}, SEL_A, SEL_C). Table 1 also shows the numbering of segments of take-off, landing and horizontal flight paths of the UAV.

Table 1

Typical take-off and landing modes of rotorcrafts UAV operations

Segm. №	Operation mode / height range	Time, sec.	Engines operating mode
Take-off of UAV			
1	Engine starting / 0 m	10	Idle
2	Climb / from 0 m to height *H*	*H*/1	Take-off
3	Hovering at height *H*	5	Hovering
h	Horizontal flight at height *H*	Determined by acoustic noticeability	Cruise flight mode
Landing of UAV			
4	Hovering at height *H*	10	Hovering
5	Helicopter-type descending from height *H* to 20 m	(*H*-20)/1	Idle
6	Hovering at 20 m	10	Hovering
7	Smooth-landing from 20 m to 0 m	40	Idle
8	Engine shutdown	5	Idle

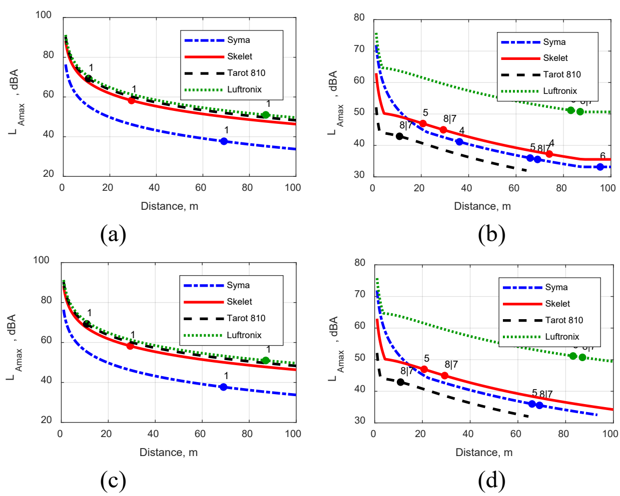

Fig. 2. Calculated maximum A-weighted noise level L_{Amax} of take-off part of trajectory up to 90 m height (a) and up to 150 m height (c), and L_{Amax} of landing from trajectory 90 m height (b) and from 150 m height (d) of rotorcraft for single operation of different UAVs types

Maximum SPrL $L_{A\max}$ at take-off (Fig 2a and 2c) are contributed mainly from the moment when UAV switches from idle to take-off mode on the landing pad. For Luftronix at 90 m take-off at large distances (more than 90 m) horizontal flight part produces greater L_{Amax} than L_{Amax} of engine take-off mode at landing pad (Fig 2a). $L_{A\max}$ at landing for small distances are the result of UAV idling at landing pad (segment 1). For larger distances (after the change of the slope of $L_{A\max}$ curve on Fig. 2b and 2c) $L_{A\max}$ is contributed from hovering (segment 3). This is the longest continuous part of $L_{A\max}$ curve (Fig. 2 b and 2c). At a distance of about 90 m, the contribution of UAV noise radiation on horizontal flight part becomes dominant for landing at 90 m height (Fig 2b). The only exception of this is Tarot810, which loses noticeability before horizontal flight part becomes important. The same situation can be observed for landing from height 150 m (Fig 2d), but horizontal flight part do not influence $L_{A\max}$ for almost all considered rotorcraft types. The only exception is Luftronix, for which horizontal flight part gives the main contribution to L_{Amax} at distances greater than 150 m.

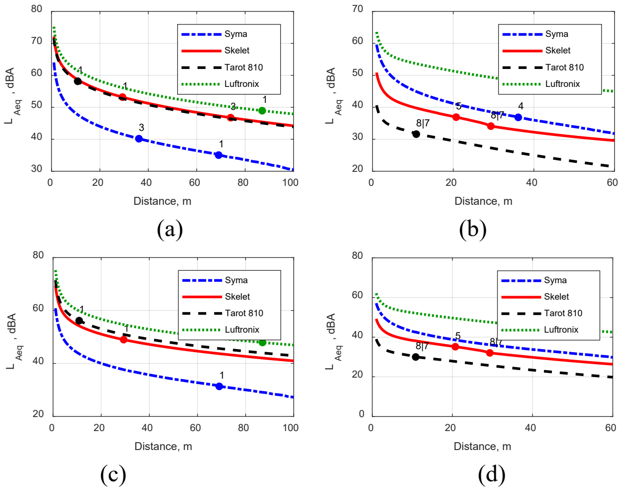

Fig. 3. Calculated A - weighted equivalent continuous sound pressure level L_{Aeq} of take-off part of trajectory up to 90 m height (a), and up to 150 m height(c), and L_{Aeq} of landing from trajectory 90 m height (b) and from 150 m height (d) of rotorcraft for single operation of different UAVs types

Points on lines indicate complete loss of noticeability at certain segments of flight. Numbers on Figs. 2–5 show the segment of UAV flight. Horizontal flight noise contribution is limited by practical acoustic noticeability of UAV operations. The segment 2 (climb) at take-off is noticeable for the distances of up to 100m, but noticeability of idling and/or hover is lost within 100m distance from landing pad.

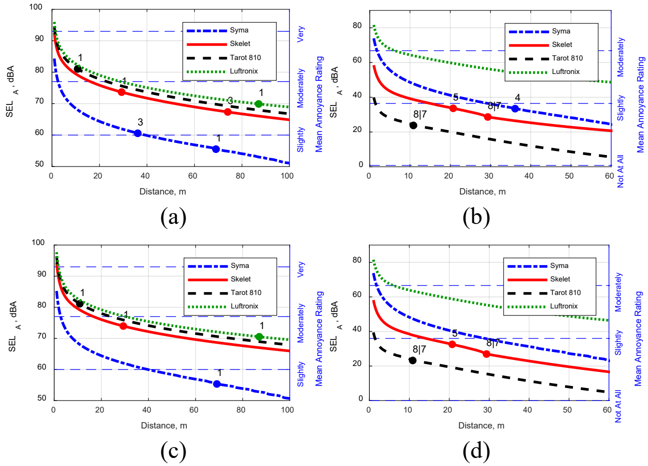

Fig. 4. Calculated A – weighted sound exposure level – SEL_A of take-off part of trajectory up to 90 m height (a), and up to 150 m height(c), and SEL_A of landing from trajectory 90 m height (b) and from 150 m height (d) of rotorcraft for single operation of different UAVs types

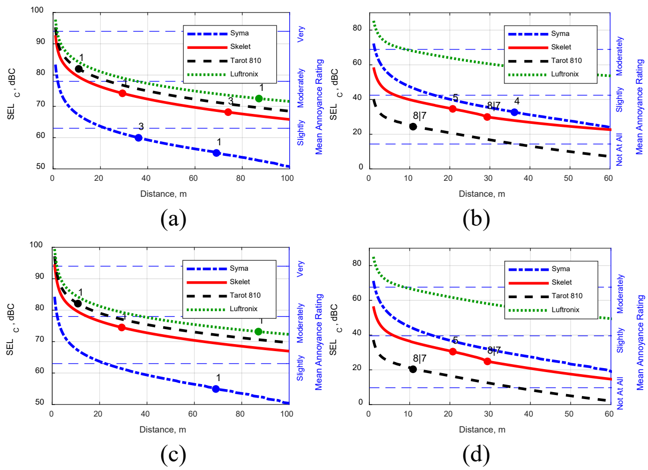

Fig. 5. Calculated C– weighted sound exposure level – SEL_C of take-off part of trajectory up to 90 m height (a), and up to 150 m height (c), and SEL_C of landing from trajectory 90 m height (b) and from 150 m height (d) of rotorcraft for single operation of different UAVs types

For UAV, which emit greater SPrL in the low and medium frequencies bands for operational flight modes (for example, Luftronix), the SEL_C metric is preferable for psychoacoustic assessing of noise effect on urban population. Therefore, the noise metric SEL_C can be used for estimation of population annoyance to UAV noise. In Figs. 4- 5 thin dashed lines define annoyance obtained by the results of research of the psychoacoustic test of UAV noise by group of subjects [2]. In the process of testing subjects were asked to rate their UAV noise annoyance using scale: not at all, slightly, moderately, very annoying. Based on the results of psychoacoustic tests, a scale developed to evaluate UAV noise. A common feature of the metrics dependence on distances (Figs. 2–5) is that the values of noise metrics for all considered types of UAV at the take-off stage significantly exceed corresponding values at UAV landing stage. This can be explained with the various techniques for piloting UAV on the considered portion of the UAV flight. Fig. 6 shows noise mapping of SEL_C for flight of small UAV at 90 m and 150 m height for background total noise SPrL of 60 dB and the following meteorological conditions: relative humidity 50 %, temperature 15°C and air pressure 760 mm Hg.

As follows from Fig.6, the noise contours SEL_C for UAV with a mass of less than 2 kg is localized in the area of the vertiports. For UAV with a mass of more than 10 kg, noise contours are observed along the UAV flight trajectory. Noise exposure due to horizontal part of flight for higher flight height is smaller along all flight trajectory, as can be seen on Fig. 6.

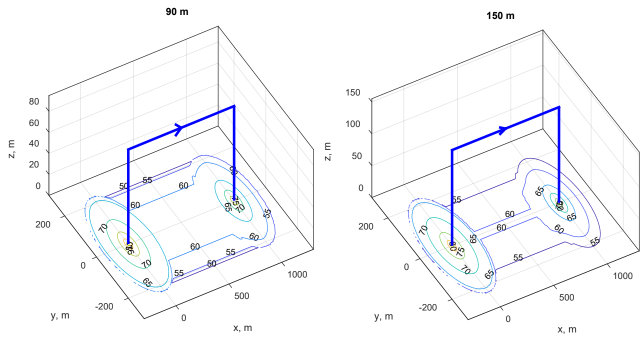

Fig.6. Contours of equal SEL_C for flight of Luftronix at 90 m and 150 m height for single UAV operation

References

1. Zaporozhets O. Determination of acoustic characteristics of Autonomous Aircrafts for environment protection and collision avoidance in flight restricted zones/ O. Zaporozhets, *V.* Tokarev, V. Makarenko// Aerospace Europe Conference AEC2020 Bordeaux, France, 25 – 28 February 2020, Session 59:594.
2. Christian A., Cabell R. (2017) ‘Initial investigation into the psychoacoustic properties of small Unmanned Aerial System noise’ in 23rd AIAA/CEAS Aeroacoustics Conference, AIAA 2017-4051, Denver, Colorado, pp. 1-21. https://doi.org/10.2514/6.2017-4051