Using Automatic Dependent Surveillance-Broadcast Data for Airport Noise Mapping

K I Kazhan

Centre of Environmental Problems of Airports, National Aviation University, Centre of Environmental Problems of Airports, 1 Liubomyra Huzara ave., Kyiv 03058, Ukraine

E-mail: kazhank@gmail.com

Abstract. The research is directed on the development of algorithm for pre-processing data to existing models of aircraft noise assessment in the vicinities of airports improving model accuracy by the means of implementation of real flight data recorder data in the local operation terms. A large effort is needed to gather, convert and adapt all the noise measured and ADS-B data needed to assess and forecast aircraft noise in the airport vicinity. The main task of the study is the development of algorithm which allows researchers to process all needed data and transform them into accurate and adequate noise maps. The results of the research improve accuracy of noise models and confirm calculated noise levels for single events during measurement campaigns. The results of the noise modelling and measurement campaign improved methodology of collection of input data combination of measured and correct implementation of measured and modelled noise data especially for noise from the single events. Experiments have shown that ADS-B data should be used to develop aircraft noise monitoring systems in the vicinity of airports and can evaluate the effectiveness of noise abatement procedures

1. Introduction

Closer distances between airports and residential areas have caused the increasing attention to the problem of aircraft noise pollution. Within the current level of aircraft noise disturbance among local communities, airport noise maps are the essential noise management tool. They form the basis for noise zoning policies and land-use planning decisions and should be considered as the basis of the ICAO Balanced Approach to Noise Management [1]. They also contribute to the development of Environmental Impact Assessments for new airport planning and airports development of Noise Action Plans according to the demands of the Directive 2002/49/EC relating to the assessment and management of environmental noise. With noise action plans, cities and municipalities have a considerable influence on the reduction of aircraft traffic noise.

Large number of noise models has been developed until now and some of them have been validated by the ICAO. The analysis of the existing noise model's efficiency and gaps (Zaporozhets, 2016) has shown that early models were based on measured data, however current methods are based on more analytical models [2]. Due to the simplifications used in the models, some differences have been identified between the calculated and measured results, especially for a single noise event [2]. The analytical method can be supplemented with a set of more practical approaches to provide a more accurate estimation of the noise indices both for individual points and for equal noise contours [2].

Noise models should combine the features of in-flight noise models and noise models from aircraft ground operations.

Important input parameters are atmospheric temperature, pressure and humidity, which can affect both the flight characteristics of the aircraft and the sound propagation [2].

The general approach to the development of aircraft noise map includes few stages:

- Noise modeling for single events
- Integration of single movements into the multiple repeated events in accordance with desired noise indices
- Plotting the noise contours and putting them onto the map of the airport's vicinity
- Development of noise restricted zones.

Each stage of the approach can be repeated several times for current scenarios and forecasting operational conditions.

Introduction of ADS-B transponders allows scientists and public to analyze flight movement data through flight tracking websites as FR24 or others or by developing own ADS-B observation system. Thanks to ICAO and EU requirements and recommendations to install ADS-B transponders on all large aircraft by 2020 the quality of the input data for noise model has increased rapidly.

Extensive input data on meteorological conditions, aircraft type, magnetic course, flight tracks and movements is a key requirement for adequate noise modeling comparable with results of measurements. A large effort is needed to gather, convert and adapt all the noise measured and ADS-B data needed to assess and forecast aircraft noise in the airport vicinity. Thus the main task of the study is the development of algorithm which will allow researchers to process all needed data and transform them into accurate and adequate noise maps.

Research on ADS-B data preprocessing has obtained significant advances and different approaches have been proposed in recent years. Pretto M. et al. (2020) presented scenario approach for airport noise based on the collection and processing of web data including FlightRadar24 and Flightaware Data. However, the time interval for displaying radar data on web resources is 15 seconds [3], and the average duration of a noise event is 40-60 seconds, thus, more accurate data in terms of time is needed to analyze the results of noise measurements.

Another branch of researches is directed on data synthesis and highlighting the operational routes in the airport vicinities (I.L. Verbraak et al., 2017; Zh. Wang et al, 2017) [4, 5]. Some of them were devoted to optimization problems (spatial management of aircraft for noise and fuel flow reduction) based on data from ADS-B receivers: optimization of noise abatement aircraft routes (Ho-Huu et al.2017, Y. Saito et al. 2019) [6-9].

2. Analysis and pre-processing of ADS-B Data for Noise Modelling

Mode-S and ADS-B are technologies that have been developed to eventually replace the Primary Surveillance Radars which tracks all flying objects in the airspace.

In accordance with Technical Report [10] Mode-S is a secondary surveillance radar technique that allows an aircraft to be selectively interrogated using a unique 24-bit aircraft address; "S" in Mode-S refers to the selective request mode. The assignment of a unique 24-bit ICAO address is a fundamental concept for Mode-S Elementary Surveillance. This eliminates the risk of confusion or misidentification due to overlapping signals. ADS-B improves safety by making aircraft visible in real time and providing position and speed data to the ATC and other appropriately equipped ADS-B aircraft. It also provides a data infrastructure for low-cost flight tracking, planning and flight dispatch [10]. ADS-B receivers can obtain several types of data messages (Figure 1).

Message type	Downlink Format	Content
ADS-B (56 bits)	DF0	Short air to air ACAS (BDS 0.E)
	DF4	Surveillance altitude
	DF5	Surveillance identity
	DF11	Mode-S only all call reply
ADS-B ES (112 bits)	DF17	Airborne position (BDS 0.5) Surface position (BDS 0.6) Extended squitter status (BDS 0.7) Aircraft type and ID (BDS 0.8) Airborne velocity (BDS 0.9)
Mode-S EHS	DF20	altitude reply: (BDS 4.0/5.0/6.0)
Mode-S EHS	DF21	identity reply: (BDS 4.0/5.0/6.0)

Figure 1. Types of ADS-B messages. *Source http://bibliotheek.knmi.nl/knmipubTR/TR336.pdf.*

The ADS-B data include (amongst others) the following information important for noise modeling:

- Unique 24-bit aircraft address
- Aircraft identification:
- Aircraft latitude/longitude
- Aircraft altitude
- Aircraft speed
- Aircraft magnetic course

Knowledge of aircraft type operating is a major requirement to estimate the acoustical impact of an airport on the community. It is a mandatory entry for both, models computing noise contours around airports such as ECAC, FAA, ICAO and aircraft noise certification procedures. The flight path is also required as there are several elements that depend on the aircraft position with relation to the observer, such as lateral attenuation, that is determined by the airplane bank angle, the elevation angle and the lateral distance to the receiver [11].

The ADS-B data' formats were defined by standards and certification documents, including EASA AMC 20-24 [12] and CS-ACNS approved with ED Decision 2013/031/R [13].

The figure 2 illustrates necessary connection for effective data preprocessing in terms of aircraft noise modeling.

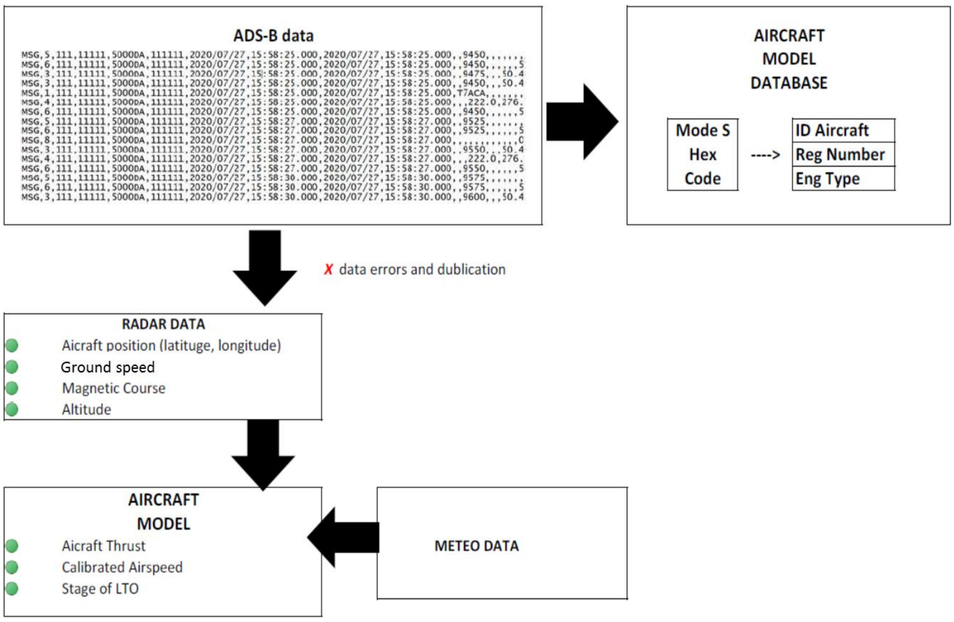


Figure 2. Scheme of the Aircraft Model Database, ADS-B data exchange.

It is possible to use any of the free available aircraft model database to define registration number of aircraft and identify aircraft type. However to get some important aircraft performance data more sophisticated approach included Aircraft Model and data clustering algorithms should be used.

2.1. Aircraft Dynamic Model

According to the ICAO DOC 9911 [14] the movement of the aircraft is determined using a point mass model with four degrees of freedom, which describes the movement of the aircraft along three perpendicular axes, and it is assumed that, as it rolls, forces are applied at the aircraft's center of gravity. The model can also be expressed using a system of ordinary differential equations [13-14]. This model relies on several assumptions: 1) there is no wind present and ISA used, 2) the Earth is flat and non-rotating [15]. The equation of the center of mass [16]:

$$m\frac{d\vec{V}_k}{dt} = \vec{R}_a + \vec{P} + \vec{G},$$

where m is an aircraft mass; V_k is airspeed; t is current time; $\vec{R}_a$ is the main vector of aerodynamic forces; $\bar{P}$ is power thrust.

The system of balanced motion of aircraft includes the following differential equation [8]:

$$\frac{dx}{dt} = V\sin\varphi\cos\gamma;$$
$$\frac{dy}{dt} = V\cos\varphi\cos\gamma;$$
$$\frac{dh}{dt} = V\sin\gamma;$$
$$\frac{d\varphi}{dt} = \frac{g\tan\theta}{V\cos\varphi};$$
$$\frac{dV}{dt} = \frac{T-D}{m} - g\sin\varphi;$$
$$\frac{dm}{dt} = f_{fuel}(T, h).$$

At a condition of low altitude and speed, equivalent airspeed V_{EAS} can serve as an appropriate replacement for an indicated airspeed, and can be derived from the true airspeed V_{TAS} by the following equation:

$$V_{EAS} = V_{TAS}\sqrt{\rho/\rho_0},$$

where ρ is the ambient air density, and ρ_0 is the air density at sea level.

2.2. Track Dispersion

Where possible, definitions of lateral dispersion and representative sub-tracks should be based on relevant past experience from the study airport, i.e. normally via an analysis of radar data samples [9]. The first step is to group the data by route. Departure tracks are characterized by substantial lateral dispersion which, for accurate modelling, has to be taken into account. It is usually sufficient to represent all arrivals by a single track because arrival routes are usually grouped into a very narrow swath around the final approach path. However, if the approach swathes are wide within the region of the noise contours they may need to be represented by sub-tracks in the same way as departure routes. It is possible to use procedural step track, where aircraft coordinates are needed (Figure 3a) or a modern navigation technology known as required navigation performance (RNP) (Figure 3b) [8].

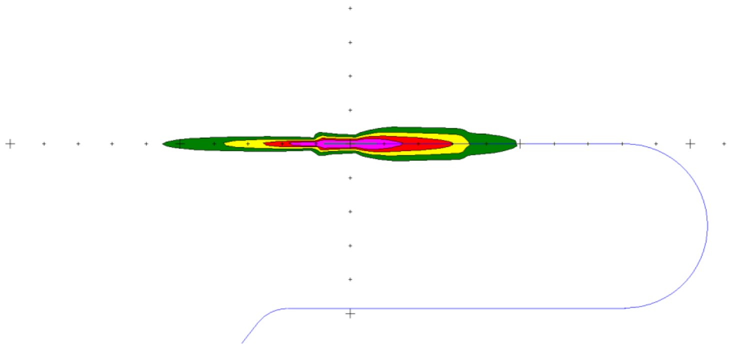
(a) (b)

Figure 3. Approaches to track description: (a) example of point-to-point track (by flightradar24.com); (b) required navigation performance by ICAO DOC 9911

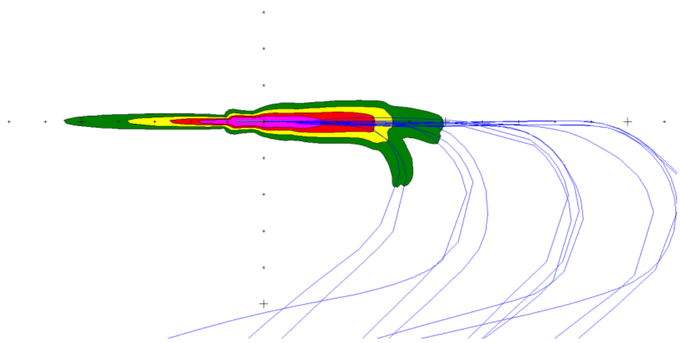
The noise modelling and measurement campaign has been started in summer 2020 for three airports in Ukraine with very different operating conditions: Antonov-1 airport (Gostomel'/ UKKM); Antonov-2 airport (Sviatoshyn/UKKT) and Dnipro Airport (UKDD).

Information that has been obtained through flight tracking includes: the flight number; the name of the airline; the actual departure time; the actual arrival time; information on the type of aircraft; flight altitude; ground speed and latitude - longitude positions. The ADS-B receiver for the purposes of short-term aircraft noise measurements was developed by the scientific group of engineers and scientists from National Aviation University. The hardware and software complex, which is under development, will allow real-time recording of aircraft tracks and creating a historical database for revision in the future.

The difference between nominal (AIP tracks) and operation tracks (flightradar24.com, Flightaware.com and NAU's receiver data) for example of A320 is demonstrated on figure 4.



(a)



(b)

Figure 4. Comparison noise contours L_{Amax} from nominal AIP Track (a) and Radar Tracks (b): A320, departure procedure, UKDD (2019-2020)

The flight path estimation method lies in statistical analysis of radar information and ADS-B data.

To cluster flight recorder track and to assess the level of dispersion the density-based spatial clustering of applications with noise (DBCSAN) method was proposed as one the most effective pre-processing step [5] before data input into aircraft noise models and noise forecasting.

DBSCAN is a commonly used density-based clustering algorithm (Figure 5). The core concept of DBSCAN is to evaluate the density according to the number of points within the ξ-neighbourhood. DBSCAN classifies the points into three types: core point, density-reachable point and noise point. The algorithm expands to density-reachable areas from a selected core point, then obtaining a maximum area including the core point and density-reachable points. Being robust to the quality of datasets, DBSCAN can divide the dataset into several clusters and noises, where the a-priori selection of the number of clusters is not required. Besides, DBSCAN is able to find arbitrarily shaped clusters. The advantages of DBSCAN make it well fitting with trajectory clustering scenarios [6,7].

Algorithm Description

For specified values of the epsilon neighborhood `epsilon` and the minimum number of neighbors `minpts` required for a core point, the `dbscan` function implements DBSCAN as follows:

1. From the input data set X, select the first unlabeled observation x_1 as the current point, and initialize the first cluster label C to 1.
2. Find the set of points within the epsilon neighborhood `epsilon` of the current point. These points are the neighbors.
   a. If the number of neighbors is less than `minpts`, then label the current point as a noise point (or an outlier). Go to step 4.

   Note

   `dbscan` can reassign noise points to clusters if the noise points later satisfy the constraints set by `epsilon` and `minpts` from some other point in X. This process of reassigning points happens for border points of a cluster.

   b. Otherwise, label the current point as a core point belonging to cluster C.
3. Iterate over each neighbor (new current point) and repeat step 2 until no new neighbors are found that can be labeled as belonging to the current cluster C.
4. Select the next unlabeled point in X as the current point, and increase the cluster count by 1.
5. Repeat steps 2–4 until all points in X are labeled.

Figure 5. Algorithm Description by MATHWORKS Help Center https://uk.mathworks.com/help/stats/dbscan-clustering.html

Experience has shown that flight track maps are the basic aircraft noise information tool. Providing people with an indication of where aircraft fly effectively underpins all other aircraft noise information. On the basis of flight path track the Flight path movement's charts should be developed in consultation with the public to overcome some of the perceived weaknesses of flight track maps. They can show a 'macro' picture of aircraft noise distribution around an airport [5].

2.3. Flight Profiles

The flight profile is a description of the aeroplane motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting [14]. Aircraft flight profiles should be defined to meet the requirements of the modelling application. In order to achieve high accuracy, the profiles should closely reflect the aircraft operations they are intended to represent. When the aircraft mass is known, the variation of speed and propulsive thrust can be calculated via a step-by-step solution using the equations of motion. Before doing so, it is helpful to pre-process the data to minimize the effects of radar errors by redefining the profile with straight line segments to represent the relevant stages of the flight; with each segment being appropriately classified, i.e. as a ground roll, constant speed climb or descent, thrust cutback, or acceleration/deceleration with or without flap change.

Common performance parameter models include [16-18]: ANP and BADA. ANP is mainly used in the field of aviation noise assessment, its strengths are the division of take-off climb and descent approach phases, and the ability to model aircraft thrust more accurately. BADA is the basic data of aircraft, which is the most widely used.

The measurements at Antonov airports were obtained during more than 3 months with various meteorological and operational conditions. The meteorological parameters were obtained from meteorological aerodrome reports (METAR). These values are determinant to calculate the speed of sound and transform NDP-profiles according to operational conditions.

Overall, over 60 recorded take-offs and arrivals were achieved, performed by aircraft types such as AN225 (Figure 6), AN124, AN22, AN74, B737, H130, IL76, AN26, AN28 and AN148. The take-off/arrival time, aircraft type, airline and flight number were provided by the airports' responsible staff (UKKM and UKTT). This information was cross-checked with data observed during the ADS-B messages receiving.

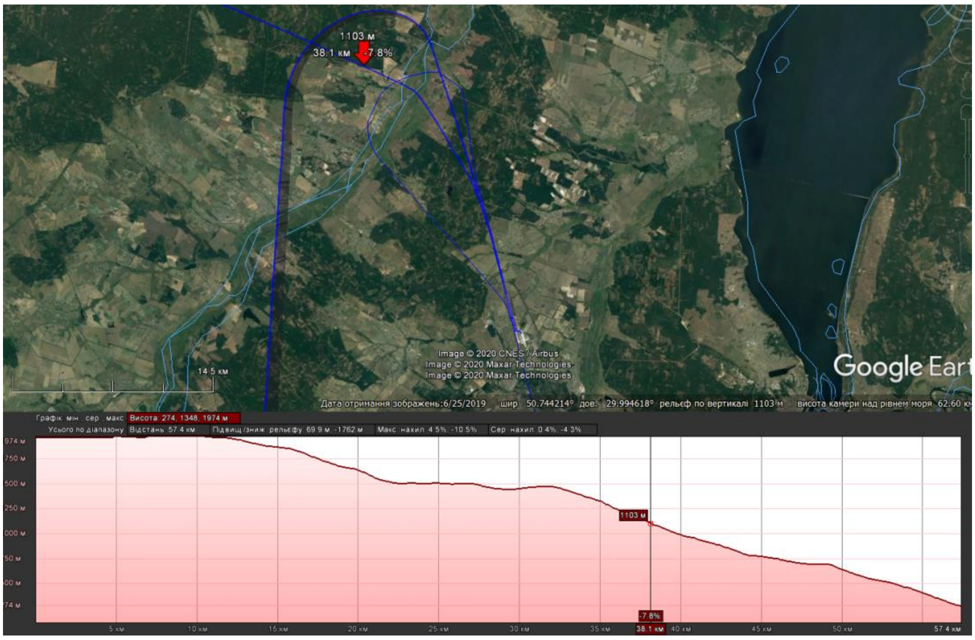


Figure 6. Data visualization for An225 departure procedures, UKKM, summer 2020.

3. Discussion

At the first stage of this study, several airports in Ukraine were selected to consider individual cases and identify all the difficulties, including organizational and managerial ones. There are two Antonov DB airports in Kyiv: Antonov-2 is more operated (outside the city) including freight and training flights. Antonov-1 is rarely exploited for only purposes of test flights and aircraft repair and overhaul.

The project had started in May 2020 with the series of AN-225 flights and continued up to October 2020. The feature of the Antonov airports is the rare event.

That was a certain challenge to organize correct measurements in conditions of low flight frequency and with a fairly conventional schedule. So this requires special efforts and even not only from our CEPA team, but also from the air traffic controllers, managers and people from the aerodrome service and even from the captain of aircraft. We are very grateful to Antonov design bureau for this support.

And of course, the special fleet of these airports should be taken into account - some planes are the only ones in the world and thus their acoustic and operation characteristics are poorly described. For example, it is hard to find AN225 in ANP data base, even in substitution part.

From methodological perspective measuring method and field research, comparison method, analysis method, and description method were used.

Sound level meters (OCTAVA 110A) were placed perpendicular to the takeoff path, starting 1 km from the closest runway end to a distance of 7 km. For landing microphones were placed perpendicular to the landing tracks starting 4 km away from the closest runway end, and to a distance of 1 km (Figure 7).

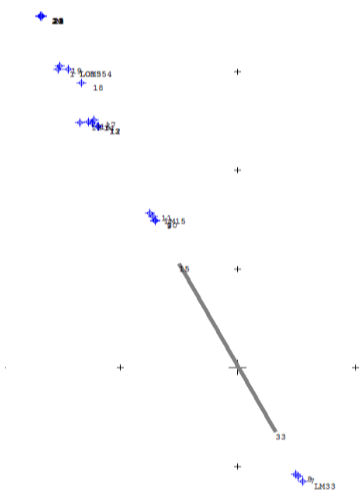


Figure 7. Measurements' sites in the vicinity UKKM, 2020

An aircraft's spatial location was determined using ADS-B receiver, combined with FR24 data, and supported by data obtained from the air traffic control personnel. Noise measurement results, aircraft tracking data and meteorological conditions were synchronized in time and space (distance from noise level measurement points). ADS-B data were recorded at 1-second intervals for NAU ADS-B receiver and for FR24 – at 15 second interval. Test flights were performed using Antonov aircraft types including: AN225, AN124 and some smaller aircraft (Figure 8).

The obtained results allow CEPA researchers to correct the modeling results for the development of the restriction zones, especially for the L_{Amax} criterion, which is normative in Ukraine - especially the levels of 70-75 dBA - at night.

The takeoff distance of 19 km is maintained only in 40% of cases, so it is worth forming using the DB Scan algorithm.

The analysis of results (table 1) has shown that if the measurement point was under the flight trajectory in the high field levels, the gap between the simulation results (given the classical approach to noise modeling - AIP data instead of real routes, scheduled flights instead of real ones, etc.) and the measured results is minimal, but if we talk about points that are remote from the airport, then we get a larger deviation for which obviously correction is required.

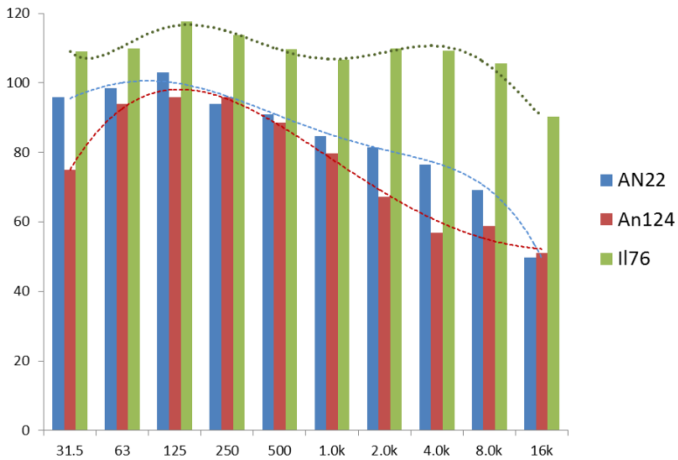


Figure 8. Averaged frequencies profiles of aircraft types: AN22, AN124, Il76

Table 1. Comparison of the calculated and measured results L_{Amax} for AN124 departure operations

N	Operation type	Latitude	Longitude	A/D	L_{AMaxF}, dB	L_{Amax} (calc), dB	Average	St Deviation
1	D	50.650556	30.153639	D	85.4	92.5	-	-
2	D	50.513861	30.257694	D	84.9	80.7	-	-
3	D	50.569083	30.216028	D	92.8	95.9	99.0	3.56
4	D	50.569083	30.216028	D	100.9	95.9		
5	D	50.569083	30.216028	D	100.8	95.9		
6	D	50.569222	30.215833	D	101.3	95.9		
7	D	50.581972	30.207000	D	100.8	101.9	100.9	1.10
8	D	50.582306	30.206389	D	102.3	102		
9	D	50.625056	30.175167	D	100.3	102.9		
10	D	50.625139	30.175278	D	99.2	102.5		
11	D	50.626333	30.174000	D	101.8	101.7		
12	D	50.640889	30.162583	D	92.1	95.3	95.1	1.10
13	D	50.640972	30.162500	D	100.1	95.2		
14	D	50.641500	30.161278	D	99.4	94.8		
15	D	50.641611	30.158528	D	92.5	93.1		
16	D	50.641750	30.160417	D	88.9	94.4		
17	D	50.642056	30.161583	D	97.4	94.9		
18	D	50.648250	30.158861	D	67.3	93.4	-	-
19	D	50.651167	30.153889	D	92.5	92.6	-	-
20	D	50.659444	30.149722	D	95.6	93.4	-	-
21	D	50.659500	30.149917	D	87.3	91.2	93.4	3.84
22	D	50.659500	30.149917	D	94.5	91.2		
23	D	50.659500	30.149917	D	93.9	91.2		
24	D	50.659583	30.149722	D	99.2	91.2		
25	D	50.659611	30.149917	D	92.2	91.2		

Conclusion

The current research is directed on the development of efficient and simple algorithm of pre-processing data to existing models of aircraft noise assessment in the vicinities of airports improving model accuracy. The research is being at the stage of processing of noise measurement and tracking results however the general stages of the algorithm has been defined and the methodology has been substantiated. The expected outcomes are the following:

- Correction NDP-data for ANTONOV airplanes;
- Development of the airport noise maps for Antonov-1 airport (Gostomel'/ UKKM); Antonov-2 airport (Svyatoshyn/UKKT) and Dnipro Airport (UKDD) based on real operation data, meteorological conditions and the results of noise measurement for single events.
- Improvement of exiting noise model through the correction of NDP-data and the development of recommendations that will allow implementing ICAO DOC 9911 methodology for single noise events at airports with low frequency of noise events.

References

[1] ICAO DOC 9829. Guidance the Balanced Approach to Noise Management. ICAO 2008, 134 p

[2] Zaporozhets O 2016 Aircraft noise models for assessment of noise around airports – improvements and limitations. *On board a Sustainable Future, ICAO Environmental Report 2016* pp 50-55 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2016/ENVReport2016_pg50-55.pdf

[3] Pretto M, Giannattasio P, De Gennaro M et al. 2020 Forecasts of future scenarios for airport noise based on collection and processing of web data. *Eur. Transp. Res. Rev*. 12, 4 (2020). https://doi.org/10.1186/s12544-019-0389-x

[4] Verbraak T L, Ellerbroek J, Sun J and Hoekstra J M 2017 Large-Scale ADS-B Data and Signal Quality Analysis. *12th USA/Europe Air Traffic Management Research and Development Seminar 2017* http://resolver.tudelft.nl/uuid:566304e6-99df-4164-96b3-6f73e6b958d7

[5] Wang Zh, Liang M and Delahaye D 2017 Short-term 4D Trajectory Prediction Using Machine Learning Methods. SID 2017, *7th SESAR Innovation Days*, Nov 2017, Belgrade, Serbia. ⟨hal-01652041⟩ https://hal-enac.archives-ouvertes.fr/hal-01652041/document

[6] Algorithm Description by MATHWORKS Help Center https://uk.mathworks.com/help/stats/dbscan-clustering.html

[7] Luo T, Zheng X, Xu G, Fu K and Ren W 2017An Improved DBSCAN Algorithm to Detect Stops in Individual Trajectories. ISPRS *Int. J. Geo-Inf.* 6 63 https://doi.org/10.3390/ijgi6030063

[8] Ho-Huu V, Hartjes S, Geijselaers L H, Visser H G and Curran R 2017 Optimization of noise abatement aircraft terminal routes using a multi-objective evolutionary algorithm based on decomposition. *6th CEAS AIR & SPACE Conf. Aerospace Europe 2017*. 16-20 Oct 2017, Bucharest, Romania https://doi.org/10.1016/j.trpro.2018.02.014

[9] Saito Y, Yoshimura S, Inoue M, Takahashi M, Sugihara Y 2019 Optimal Trajectory Planning of Aircraft for Fair-Sharing of Noise. *IFAC PapersOnLine* **52** 8 pp 271-276

[10] Haan S, Haij M and Sondij J 2013 Technical Report TR-336: The use of a commercial ADS-B receiver to derive upper air wind and temperature observations from Mode-S EHS information in The Netherlands. Version 1.0 http://bibliotheek.knmi.nl/knmipubTR/TR336.pdf

[11] Sánchez-Pérez L Al, Sánchez-Fernández L Pa, Suárez-Guerra S, Márquez-Molina M 2014 Geo-referenced flight path estimation based on spatio-temporal information extracted from aircraft take-off noise. *Digital Signal Processing* **30** 2014 1-14, ISSN 1051-2004, https://doi.org/10.1016/j.dsp.2014.03.004

[12] EASA AMC 20-24 Certification Considerations for the Enhanced ATS in Non-Radar Areas using ADS-B Surveillance (ADS-B-NRA) Application via 1090 MHZ Extended Squitter https://www.easa.europa.eu/sites/default/files/dfu/Annex%20II%20-%20AMC%2020-24.pdf

[13] EASA ED Decision 2013/031/R https://www.easa.europa.eu/sites/default/files/dfu/2013-031-R-ED%20Decision%202013-031-R.pdf

[14] ICAO, Doc 9911 Recommended Method for Computing Noise Contours Around Airports, 2008

[15] Sun J, Hoekstra J M and Ellerbroek J 2020 OpenAP: An Open-Source Aircraft Performance Model for *Air Transportation Studies and Simulations. Aerospace 7(8)* p 104 https://doi.org/10.3390/aerospace7080104

[16] Levchenko L O 2020 Modeling and forecasting the distribution of aircraft noise, electromagnetic fields around the airport, substantiation of means of their normalization. National Aviation University (Kyiv) http://er.nau.edu.ua/handle/NAU/43070 (in Ukrainian)

[17] Chaoyue L, Zheng Q, Chang J and Li Y 2020 Summary and outlook of 4D track prediction methods *J of Mech Eng, Automation and Control Systems,* **1** 1 2020 pp 46-55 https://doi.org/10.21595/jmeacs.2020.21553

[18] Kartyshev M O 2019 Using Flight Data Recorder Data to Determine Aircraft Noise Levels in the Vicinity of Airports. The ICAO Environmental Report 2019 https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg66-71.pdf