

INTEGRATING ADS-B DATA FOR ENHANCED AIRPORT NOISE MODELING AND ENVIRONMENTAL MANAGEMENT

Kateryna Kazhan  0000-0002-5668-9965

State University 'Kyiv Aviation Institute', 1, Liubomyra Huzara Ave., Kyiv, Ukraine

ABSTRACT

Although the COVID-19 crisis reduced the total number of people suffering from aviation noise, along with significant noise reduction achieved through the effective implementation of the ICAO Balanced Approach, aviation noise continues to be a sensitive environmental factor for local communities. Developing a comprehensive management strategy requires realistic input data for accurate noise modeling and management.

This study explores the integration of ADS-B data to improve aviation noise management and multicriteria optimization. The maximum entropy approach is applied to incorporate environmental and operational interrelationships, including noise criteria from various sources. This proposed methodology presents a holistic approach that unites aviation noise modeling, monitoring/measuring, and management to identify and substantiate the best noise reduction practices for a specific airport.

The study specifically examines the sensitivity of noise modeling results to realistic flight tracks (ADS-B data) for urban airports in Ukraine, focusing on both lateral (approach and departure stages) and vertical dispersion. Test cases are outlined to demonstrate the efficiency of the entropy-based optimization model.

Keywords

Aircraft noise, ADS-B data, noise forecasting, entropy optimization.

List of symbols

- $i=1 \dots N_i$ – index of aircraft types in operation, where N_i is the total number of aircraft types;
- $j=1 \dots N_j$ – index of departure-arrival tracks, where N_j is the total number of tracks;
- $l=1 \dots N_l$ – index of control points (measurement points), where N_l is the total number of control points;
- $k=1 \dots N_k$ – index of noise abatement operational procedures (NAOPs), where $k=1$ represents the basic operational procedure without modifications, and $k=2 \dots N_k$ represent noise abatement procedures;
- $m=1 \dots N_m$ – index of specific period;

* Corresponding Author. Email address: kateryna.kazhan@npp.kai.edu.ua

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- Q_i – number of aircraft of type i ;
 D_j – number of aircraft on track j ;
 Z_{ij}^{kml} – contribution of aircraft of type i on track j , using procedure k during period m , to the noise level at control point l depending on noise criteria type;
 β^l – Lagrange multipliers;
 T_{ij}^{km} – distribution of aircraft operations under profile k for aircraft type i on route j during period m ;
 L_{Aij}^{kl} / L_{Aeq} – noise equivalent level at point l from aircraft type I during moving on route j using k profile;
 v_{ij}^k – a-priori coefficients, representing predefined weighting factors, which may satisfy the constraints $v_{ij}^k = \frac{\sum v_{ij}^k}{k+i+j}$, $\sum v_{ij}^k = 1$, or be adjusted to optimize specific operational parameters;
 $\ln \omega(\{T_{ij}^{km}\})$ – logarithm of the probability associated with the distribution of aircraft flights T_{ij}^{km} .

INTRODUCTION

Aviation activity has numerous adverse effects on the environment and local communities. This represents one of the most sensitive factors affecting the quality of life of local residents, making it crucial to strive to engage local communities in decision-making processes on the part of airport professionals and aviation authorities. Noise, in particular, irritates many people living near airports, detracting from their quality of life, but in addition to the issue of aircraft noise, safety, capacity, land-use planning, and other environmental factors should be considered as part of effective environmental management.

Airport noise exposure peaked before the COVID-19 outbreak [1, 2], and it may stay below 2005 levels even after the recovery from the pandemic (Fig. 1). The new EASA European Aviation Environmental Report of 2025 is less optimistic (In comparison to the previous EASA European Aviation Environmental Report of 2022) about future noise forecasting scenarios and the number of people affected. For example, it has been shown that in 2025, the forecasted number of people within the 55 dB noise contour is estimated at 3.43 million, compared to the previous EASA 2025 report, which projected a figure of around 2.7 million in high-traffic scenarios. Looking ahead to 2050, the number of people affected is expected to increase further – from 2.44 million [1] to 3.87 million people [2].

Despite the COVID-19 outbreak and the aviation industry's efforts in the field of noise reduction, a significant number of people continue to suffer from exposure to

aviation noise. According to the European Environment Agency forecast, by 2030, the expected number of highly annoyed people exposed to noise exceeding the WHO-recommended level of 55 dB is projected to exceed 1 million under an optimistic scenario (Fig. 2). Thus, the challenge of further mitigating noise in the vicinity of airports remains critical for improving the well-being of affected communities.

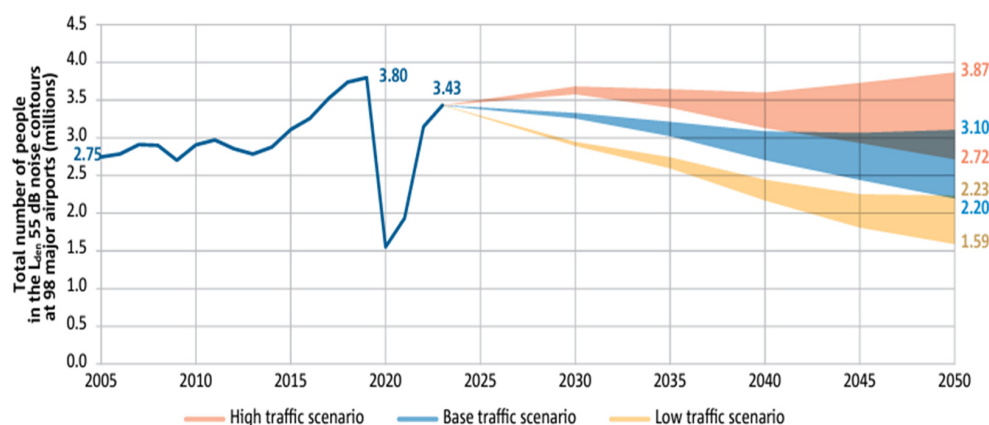


Fig. 1. Noise exposure was reduced by two-thirds between 2019 & 2020, and may stay below pre-COVID levels [2].

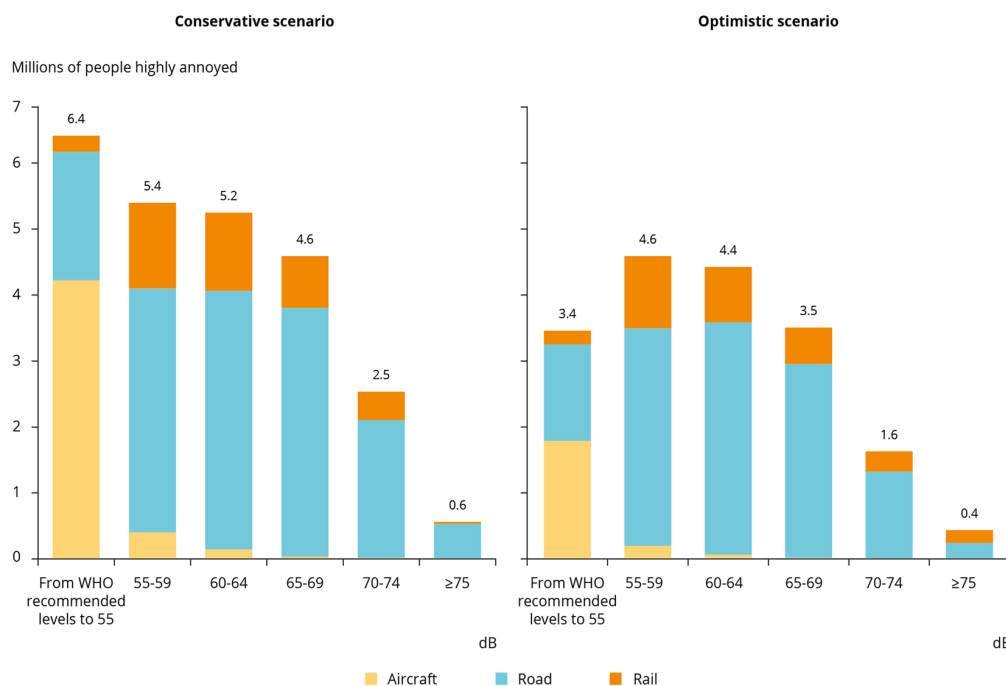


Fig. 2. Projected numbers of people highly annoyed by transport noise, by noise band and transport source, in the EU-27 under conservative and optimistic scenarios for 2030 by EEA // <https://www.eea.europa.eu/data-and-maps/figures/projected-distribution-of-people-highly>

METHODOLOGY AND OBJECTIVES

Noise modeling and noise measurement are two processes that must focus on enhancing the environmental management strategy at a given airport, rather than focusing solely on model accuracy or data convergence. However, ensuring accuracy should remain a priority.

Well-defined procedures exist for noise assessment through modeling [3,4] and noise measuring or monitoring [5]. Comparative analysis has revealed significant deviations between noise measurement data and modeling outputs [6]. These deviations are sensitive to the accuracy and quality of input data, especially for single-event noise assessments – such as L_{Amax} , currently one of the primary metrics used for noise zoning in Ukraine.

According to ECAC Doc 29 [4], in the context of modeling, a flight path (or track) is a comprehensive description of the motion of an aircraft in space and time. In the absence of radar or flight data, it is recommended to use nominal Standard Instrument Departures (SID) and Standard Terminal Arrival Routes (STAR) as specified in the Aeronautical Information Publication (AIP). In Ukraine, flight data taken from open sources (such as FR24 [7] and FlightAware [8]) or directly from ADS-B receivers were excluded from modeling for organizational reasons. This exclusion led to deviations between modeling and measurement results, as well as misunderstandings in the processes of environmental management and the dissemination of environmental information.

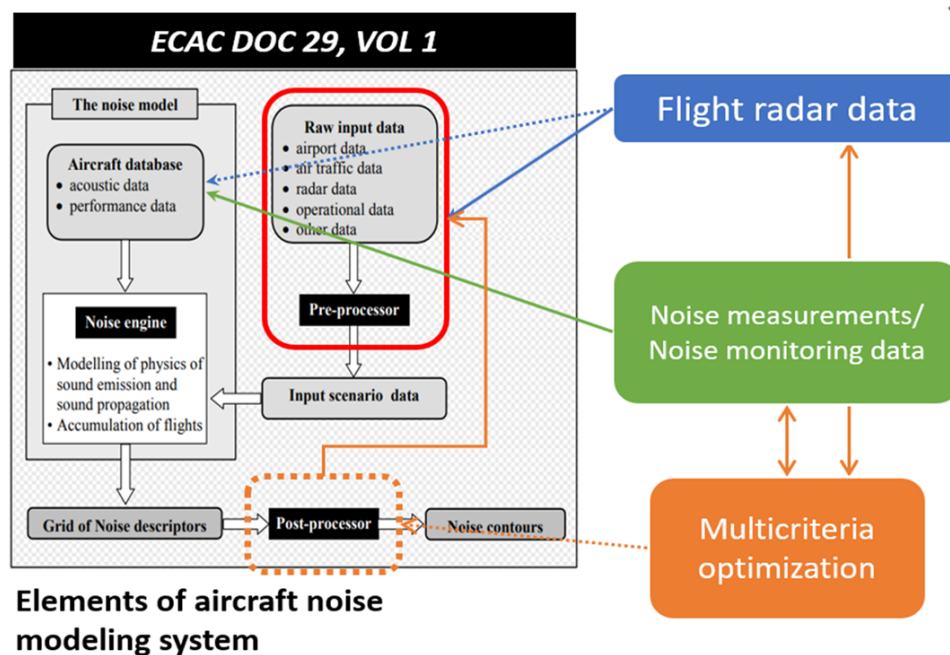


Fig. 3. The study methodology and the connection with ECAC Doc 29.

The methodology of the present study follows the principles and recommendations of ECAC Doc 29 and incorporates stages of noise monitoring, measurement, and multicriteria optimization (Fig. 3). The main objective of this study is to assess the efficiency of implementing ADS-B data in the development of a basket of measures. Additional objectives are to demonstrate how ADS-B data can be used to fine-tune regulations for modeling tasks, optimize the structure of the noise monitoring system or the location of noise measurement sites, enhance decision-making processes, and improve community engagement.

AIRPORT NOISE MAPPING AND NOISE EVENT MONITORING

Noise criteria for noise mapping and monitoring. Aircraft noise measuring and monitoring in the vicinity of an airport requires well-organized field acoustic research to achieve the main goal: reducing the population affected by noise and improving the quality of life of affected communities. According to ISO 20906:2009 [5], successful processing of monitoring data requires not only long-term measurements but also the identification, classification, and selection of sound events associated with aircraft.

Airport noise mapping should comply with Directive 49/2002 and relevant national regulations. Under this Directive, noise zoning should be determined based on the noise index L_{den} , which belongs to the group of equivalent sound levels commonly applied for zoning purposes. However, some countries in the European region apply maximum noise levels as the legislative limits (for example, Ukraine has both types of limits – equivalent (L_{Aeq}) and maximum (L_{Amax}) sound levels). The shape and area of noise protection zones (defined based on the maximum sound level L_{Amax}) are very sensitive to vertical and horizontal track dispersion, the real conditions of flight operation, etc. (Fig.4).

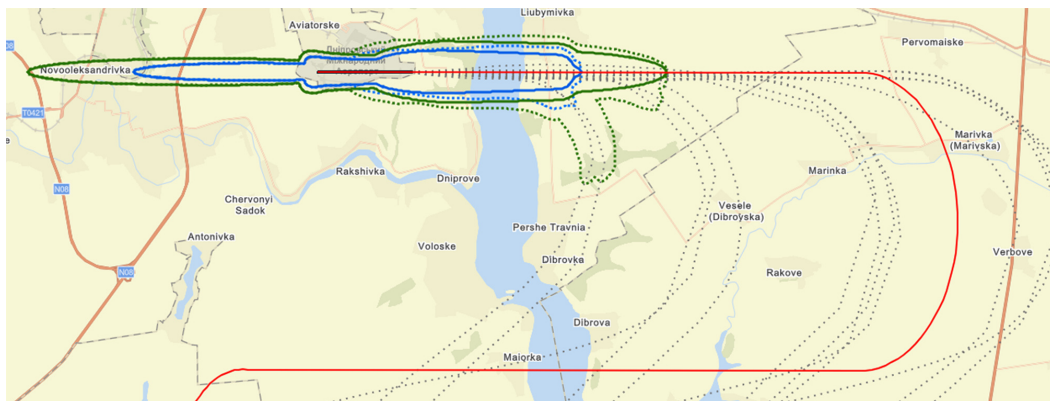


Fig. 4. Comparison of two noise zoning strategies based on L_{Amax} : solid red for AIP track; dotted grey for real ADS-B tracks, black for runway, green for $L_{Amax}=75$ dBA, blue for $L_{Amax}=80$ dBA, UKDD.

ADS-B data for noise mapping and monitoring. To clarify the results of aviation noise modeling at the airport and to explain the possible discrepancies between measured and modeled results, open track data derived from ADS-B surveillance were analyzed. According to ADS-B surveillance technology, an aircraft determines its position using satellite, inertial, and radio navigation systems and transmits it (approximately 1 sample/1 second) periodically with other relevant parameters to ground stations and other equipped aircraft. The signals are transmitted at a frequency of 1090 MHz. The receiver's ADS-B antenna is capable of receiving messages from aircraft up to 400 km away. However, for aircraft at lower altitudes, the range may be significantly limited – especially for aircraft that are on the ground, in the stages immediately before landing, or in the initial stages of takeoff [x9]. ADS-B radar recorded data include aircraft identification, position (latitude and longitude), altitude, course, and ground speed, which is well-fitted for ground tracks, but not enough for vertical or 3D profiles.

Experience at city airports. A noise measurement campaign was conducted at city and design bureau airports in Ukraine during 2020–2021. These measurements took place amidst the COVID-19 crisis at Gostomel Airport (UKMM) and Sviatoshyn Airport (UKKT), followed slightly later (autumn 2021) by measurements at Kyiv Airport (UKKK) and Borispil' (UKBP). These measurements and observations primarily aimed to validate noise maps as part of airport certification efforts, in compliance with national legislation and the requirements of Directive 49. A notable feature of the operations at Gostomel and Sviatoshyn airports was the increase in cargo transportation, particularly by Antonov aircraft, which were heavily involved in delivering medical supplies worldwide during the pandemic.

These measurements under real operational conditions at Kyiv, Gostomel, and Sviatoshyn airports also enabled the environmental efficiency of using ADS-B data to be evaluated. This analysis focused on assessing the lateral dispersion of flight tracks during departure, lateral dispersion during approach, vertical dispersion, and noise model corrections.

A. Lateral dispersion of flight track at the departure stage

Complex measurements of aircraft noise, alongside ADS-B data recording, were conducted in the vicinity of three Ukrainian airports (UKMM, UKKK, UKKT) to analyze potential discrepancies between noise measurement results, zoning, and actual operational conditions.

Figure 5a illustrates the noise zoning based on the L_{Amax} criterion for UKMM airport, utilizing AIP data on standard departure and arrival routes (blue indicates departures, red indicates arrivals). Figure 5b shows the actual flight paths recorded during the 2021 measurement campaign. An example of the comparison between measurement results and modeling based on nominal flight paths (Figure 5a) is presented in Figure 6. The maximum error observed is over 7.5 dBA, indicating the need for adjustments in modeling for specific flights, despite the measurement points

being located within 5 km from the runway end along the expected flight paths, which is attributed to significant deviations of actual flight paths from the nominal ones.

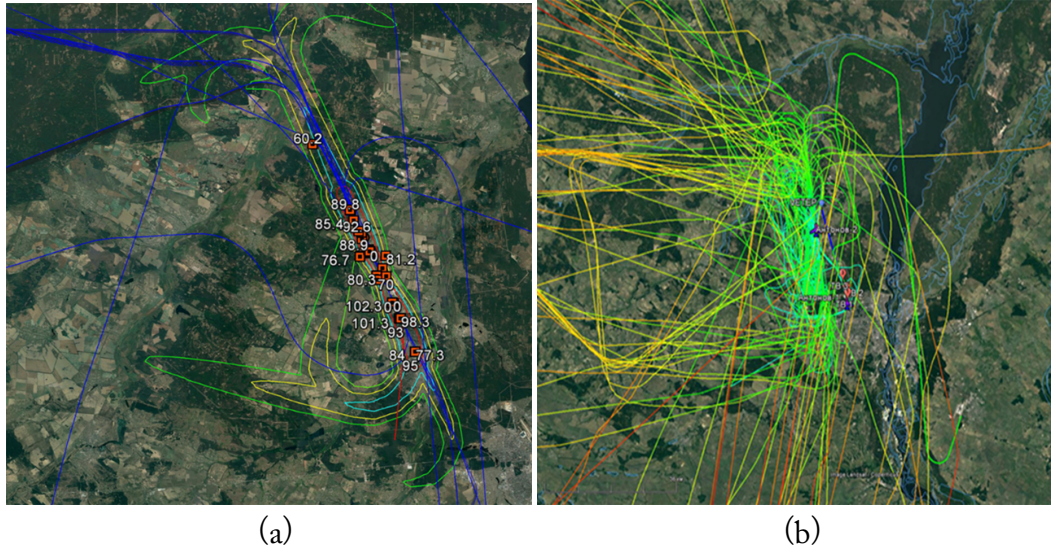


Fig. 5. Noise zoning, measurements, and ADS-B tracking at the vicinity of UKMM:
 (a) noise zoning (L_{Amax}) based on AIP nominal tracks and measurement points (red dots);
 (b) real track dispersion during summer 2021.

Thus, an important task for the take-off phase is to take into account the actual flight trajectories from ADS-B when modeling noise contours and substantiating the boundaries of residential restriction zones, as well as comparing the L_{Amax} sound levels obtained as a result of modeling and measurements.

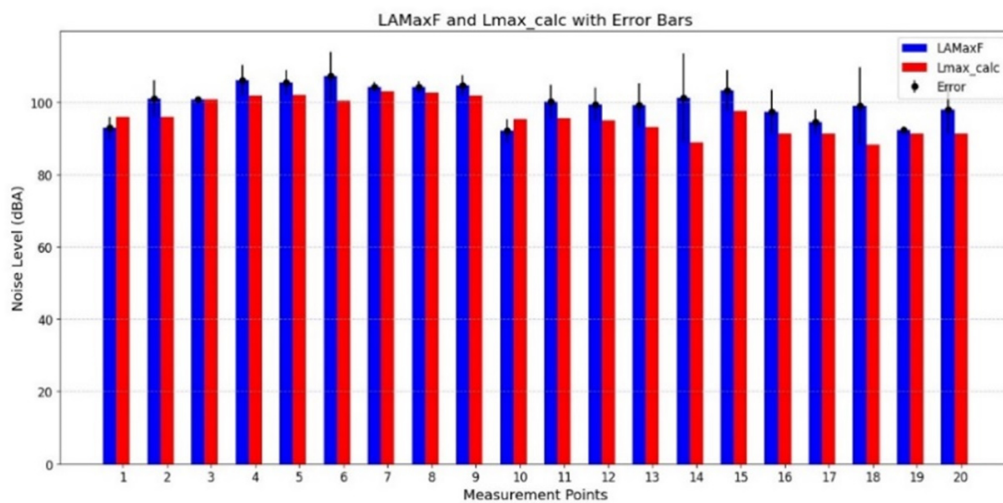


Fig. 6. Deviation between measurement results (blue) and modeling results (red).

B. Lateral dispersion of flight track during approach

For the descent and approach stages, the track dispersion is significantly lower: for example, of measurement at UKKK the deviation does not exceed 200 m at a distance of 6 km (Fig. 7) for the same flight (October–November 2021).



Fig. 7. Track dispersion (white lines) during descent and arrival procedures, typical for city airports; 70–85 dBA are L_{Amax} noise levels.

Measured arrival altitudes tend to be close to the modeled altitudes at the shorter track distances, higher than the modeled altitudes at the middle distances, and lower than those modeled at the furthest track distances (Page et al., 2009).

C. Vertical Dispersion and Noise Model Corrections.

Fig. 8 illustrates possible Vertical Dispersion for the same flight and aircraft (for example of turboprop aircraft) at UKKK. At approximately 5000 feet, the dispersion is around 200–300 feet (Fig. 8a). At 10,000 feet, the dispersion increases slightly to about 1000–1300 feet. At distances greater than 10,000 meters, variations in profiles become even more noticeable, reflecting differences in operational procedures and aircraft performance. Fig. 8b shows altitude profiles during descent, with time (in seconds) relative to touchdown. At higher altitudes (above 5000 feet), descent profiles show increasing variability. Close to touchdown, the trajectories converge, reflecting consistent approach procedures and stable descent operations. The analysis highlights discrepancies in vertical flight profiles between calculated and standard altitudes used in noise models (e.g., INM, AEDT). These differences primarily arise due to the shifted runway touchdown moments compared to AIP data, particularly regarding displaced thresholds. Such variances significantly impact Noise-Power-Distance (NPD) dependencies, altering noise predictions.

To address these issues, corrections were applied to the vertical flight profiles, and NPDs were subsequently adjusted using methodologies outlined in the referenced framework by Synodinos [10] as shown in Fig. 9. This framework emphasizes the computational derivation of NPD curves to improve alignment with real-world operational data and minimize reliance on empirical measurements.

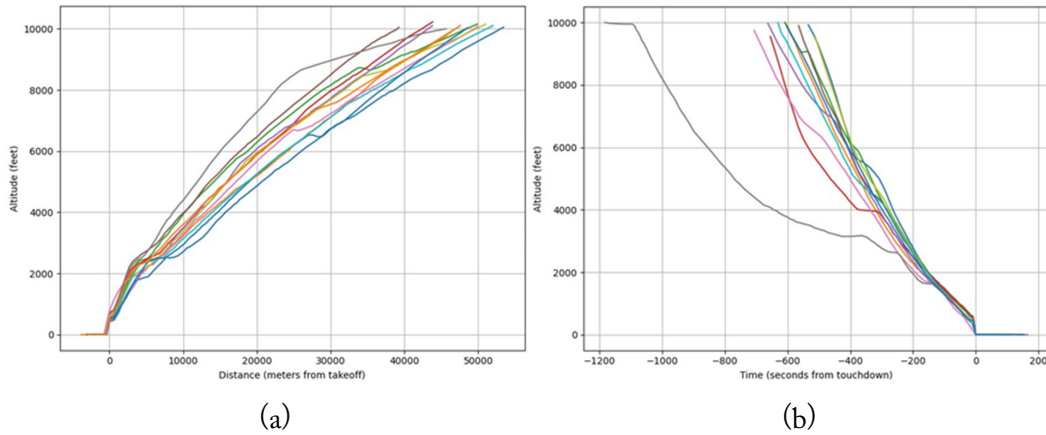


Fig. 8. Dispersion of vertical profiles during takeoff (a) and approach (b), turboprop aircraft (UKKK, 2021).

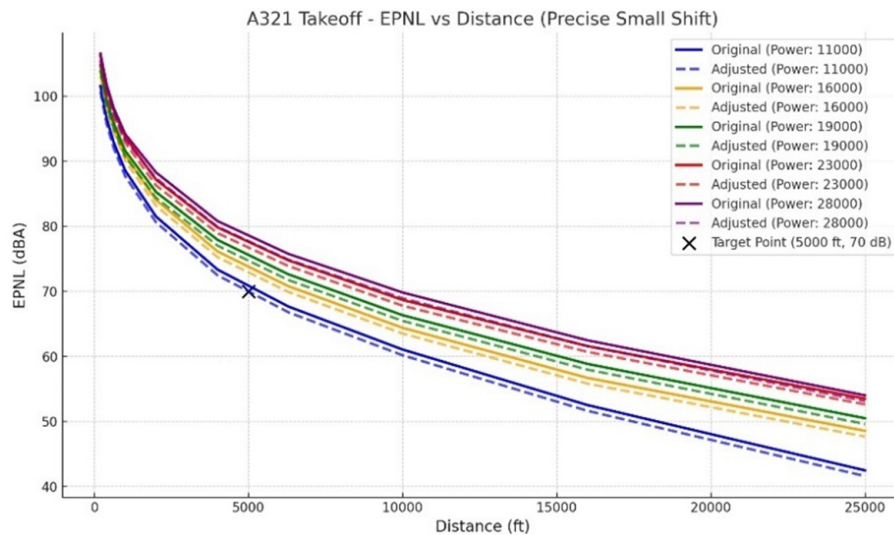


Fig. 9. Example of NPDs correction (A321) – source for original data: EASA website.

The iterative procedure used for altitude corrections ensured that the noise criteria were consistently met at critical measurement points. Furthermore, the updated NPD curves derived from the framework accounted for both vertical and lateral dispersion during critical flight phases. These enhancements resulted in better agreement between modeled noise contours and measured data.

The integration of such methodologies into standard noise modeling workflows demonstrates their potential for refining noise exposure assessments at airports, particularly those in urban settings where accurate environmental management is crucial.

The results have shown that the calculated flight altitude is higher than the standard altitude at noise models (INM, AEDT) because of the shifted moment of runway touching compared with AIP data about displaced thresholds. This causes changes in NDP dependencies. The results of the altitude and thrust correction are presented in Table 1.

Table 1. Comparison of measured and modeled data on the example of A321 (N=65, averaged measured data for approach MP2 and departure MP4).

POINT	Modelled data	Measured data	Difference	Correction	Difference (corr)
L_{Amax} , dBA					
MP2	89.4	95.2	-5.8	91.8	-3.4
MP4	84.2	88.0	-3.8	85.6	-2.4
SEL, dBA					
MP2	94.4	96.7	-2.3	95.1	-1.6
MP4	91.1	90.9	0.2	90.9	0.0

MULTICRITERIA OPTIMIZATION

The task of aircraft noise reduction in the airport vicinity is highly connected with the structure and features of the air transport system, which is becoming more unpredictable. In the near future, air transport is expected to be influenced by novel factors. Forecasted airport scenarios will be more diverse (including Urban Air Mobility – UAM, supersonic jets, electric and hybrid aircraft, etc.) and will demand novel approaches to noise mitigation, including the efficiency of noise abatement procedures (NAPs) environmental trade-offs, capacity and safety considerations (Table 2).

To effectively mitigate the impact of aircraft noise on the environment in the vicinity of an airport, it is necessary to implement all possible measures, including low-noise flight procedures, and spatial and ground management (Table 2).

Table 2. Noise abatement procedures and implementation restrictions [11].

Category of procedure	Procedures	Implementation restrictions		
		Capacity	Airport configuration and residential areas	Environmental tradeoffs
Noise abatement flight procedures	CDA	+		
	NADPs	+	+	+
	Modified approach angles			+
	Staggered, or displaced landing thresholds		+	+
	Low power/low drag approach profile	+		
	Minimum use of reverse thrust after landing	+		
Spatial management	Noise preferred arrival and departure routes	+	+	+
	Flight track dispersion or concentration	+	+	+
	Noise preferred runways	+	+	+
Ground management	Hush houses and engine run up management (location/aircraft orientation, time of day, maximum thrust level)		+	+
	APU management	+	+	+
	Taxi and queue management	+	+	
	Towing	+		
	Taxi power control (taxi with less than all engines operating)			+

To consider the environmental (noise and emission) impact of the aircraft movements by various types ($i=1\dots N_i$) of aircraft in operation, it is necessary to distribute the aircraft among the tracks ($j=1\dots N_j$) of departure/arrival according to noise level requirements in control points ($l=1\dots N_l$) (points of measurements) during specific time ($m=1\dots N_m$). Beyond the various measures of spatial management the implementation of noise abatement operational procedures (NAOPs) ($k=1\dots N_k$) provides additional means for noise control; here $k=1$ is the basic operational procedure without any modification for noise control, $k=2\dots N_k$ are noise abatement procedures (NAPs). So, the quantity T_{ij}^{km} defines the number of aircraft of type i on track j subject to the implementation of noise control measure of type k . In general, the task is to determine the quantity of aircraft T_{ij}^{km} of each type i on each track j that use the procedure k to reduce noise exposure at least till the normative level of the noise criteria will be fulfilled. The aircraft quantity T_{ij}^{km} is subject to the operational restrictions [12]:

$$\sum_{j,k,m} T_{ij}^{km} = Q_i, \quad (1)$$

and the environmental constraints, which are the prescribed levels of noise at control point l :

$$\sum_{i,j,k,m} T_{ij}^{km} \cdot Z_{ij}^{kml} = 1, \quad (2)$$

where Z_{ij}^{kml} depends on the type of noise criteria.

Thus, the matrix $T = \{T_{ij}^{km}, i=1\dots N_i, j=1\dots N_j, k=1\dots N_k, m=1\dots N_m\}$ describes macro- and micro-properties of the system. Every element of the system is considered on two levels: as a multiplicity of single aircraft T_{ij}^{km} , and as a quantity of aircraft of each type Q_i , or of aircraft used each track D_j . There are many microstates of the system which could lead to the same marcostate [10]. The target function $\ln \omega(\{T_{ij}^{km}\})$ was introduced as the maximum of entropy of the system [13]:

$$\ln \omega(\{T_{ij}^{km}\}) = \lg \left(\frac{T!}{\prod_{i,j,k,m} T_{ij}^{km}!} \prod_{i,j,k,m} (v_{ij}^k)^{T_{ij}^{km}} \right) \approx \ln T! - \sum_{i,j,k,m} (T_{ij}^{km} \ln T_{ij}^{km} - T_{ij}^{km}) + \sum_{i,j,k,m} (T_{ij}^{km} \ln v_{ij}^k) \quad (3)$$

The distribution of aircraft T_{ij}^{km} was calculated as:

$$T_{ij}^{km} = \frac{v_{ij}^k \cdot Q_i \cdot \exp(-\sum_l \beta^l Z_{ij}^{kml})}{\sum_{j,k} v_{ij}^k \cdot \exp(-\sum_l \beta^l Z_{ij}^{kml})}, \quad (4)$$

where β^l are the Lagrange multipliers.

Equation (4) was solved iteratively for the number of aircraft T_{ij}^{km} at which the noise criterion was fulfilled.

TEST CASE – OPTIMIZATION OF AIRCRAFT DISTRIBUTION AMONG ALTERNATIVE PROFILES AND NAPS BASED ON RADAR OR ADS-B DATA

To illustrate the potential of the entropy-based model, forecasting and optimization are performed for several scenarios. To demonstrate the impact of realistic operational procedures on noise levels and airport capacity, let us consider baseline scenario 0, in which five aircraft types ($i, N_i=5$: B 738, B 773, A 321, A 332 and A 340) operate across four landing routes on two parallel runways ($j, N_j=8$). One of 5 approach profiles ($k, N_k=5$) can be used as an alternative operational profile with different acoustic efficiencies (Fig. 10 shows A321 differences as an example).

Under scenario 0, noise levels at the control points $l=1...3$ exceed $L_{AeqD}=55$ dBA (Fig. 10b). It is necessary to reduce the noise levels at the control points to 55 dBA by selecting the most optimal noise reduction methods for each aircraft type under the given conditions during landing in addition to the operational constraints (Eq. 1), which include the aircraft number, $T_{\Sigma}=400$ and $Q_i=50$.

The acoustic constraints are the following:

$$\sum_{i,j,k} T_{ij}^{km} P_{ij}^{km} = 1, \quad P_{ij}^{kl} = \frac{1}{T_0} 10^{0.1L_{Aij}^{kl} - 0.1L_{Aeq}}.$$

As a result of the optimization using Eq. 4, scenario 1 is obtained.

The distribution of aircraft across ground tracks and vertical profiles are presented in Table 4, enabling noise levels in control points $l=1...3$ to be reduced to 55 dBA, as shown in Fig. 10.

The optimization results (scenario 1) allow for a 9.4% reduction in the area of noise contours corresponding to $L_{AeqD}=55$ dBA (Table 3). Noise levels L_{Aeq} were decreased by 5.6 dBA at control point 1, 6 dBA at point 2, and 4.5 dBA at point 3.

Table 3. Changes in the Areas of Equal Noise Contours in the Vicinity of the Airport for Different Operational Scenarios.

Contour Level (L_{Aeq} , dBA)	Scenario 0 [sq km]	Scenario 1 [sq km]	Change 0→1 [%]
55	351.58	318.45	-9.43
65	91.78	83.92	-8.56
75	13.70	13.62	-0.58
85	2.30	2.37	+3.04

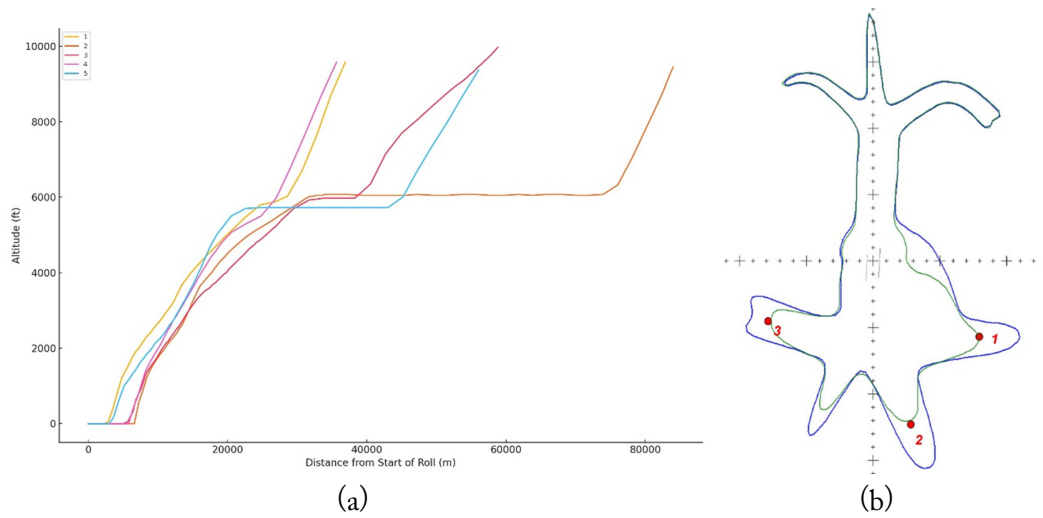


Fig. 10. Vertical dispersion during A321 departure stage (2021, UKBP), $k=1 \dots 5$ (a); noise modeling results $L_{Aeq} = 55$ dBA for scenario 0 (blue contour) and scenario 1 (green contour), 1-3 – control points (b).

Table 4. Modeling results: optimal distribution T (scenario 1) aircraft types, vertical profiles and tracks during the landing phase compared to scenario 0.

Aircraft Type (i)	Route (j)	1	2	3	4	5	6	7	8
1, B 738	$k=1/2/3/4/5$	10/0/0/0/0	7/1/1/1/1	8/1/1/1/1	5/1/1/0/1	5/1/1/0/1	7/1/1/1/1	8/1/1/1/1	6/1/1/0/1
2, B 773	$k=1/2/3/4/5$	10/0/0/0/0	8/1/1/1/1	8/1/1/1/1	5/1/1/0/1	5/1/1/0/1	8/1/1/1/1	8/1/1/1/1	5/1/1/0/1
3, A 321	$k=1/2/3/4/5$	10/0/0/0/0	8/1/1/1/1	8/1/1/1/1	5/1/1/0/1	5/1/1/0/1	8/1/1/1/1	8/1/1/1/1	5/1/1/0/1
4, A 330	$k=1/2/3/4/5$	10/0/0/0/0	9/1/1/1/1	9/1/1/1/1	4/1/1/0/1	4/1/1/0/1	9/1/1/1/1	9/1/1/1/1	4/1/1/0/1
5, A 340	$k=1/2/3/4/5$	10/0/0/0/0	9/1/1/1/1	9/1/1/1/1	3/1/1/0/1	3/1/1/0/1	9/1/1/1/1	9/1/1/1/1	4/1/1/0/1

Thus, the entropy-based approach enables the determination of the optimal distribution of aircraft across routes and operational modes while considering potential operational constraints, such as the total delay duration at the airport or the delays for each aircraft type.

CONCLUSIONS

The study analyzed the significant discrepancies that arise between noise modeling results and real-world noise measurements under operational airport conditions. The integration of ADS-B data allowed for the consideration of both vertical and horizontal dispersion of flight trajectories, improving the accuracy of noise modeling and the identification of noise protection zones. Adjusted altitude and thrust profiles demonstrated a reduction in noise levels at control points by an average of 3–5 dBA. These findings highlight the importance of integrating real flight trajectory data for effective noise management near airports.

The entropy-based approach proved effective in optimizing aircraft distribution across tracks and altitude profiles. In the optimized scenario (Scenario 1), the area of 55 dBA noise contours was reduced by 9.4%, while noise levels at key control points decreased by 4.5–6 dBA.

The proposed methodology demonstrates the potential for integrating ADS-B data and multi-criteria optimization methods to create more accurate models and develop noise management strategies. This is particularly relevant for airports located in urban areas, where strict compliance with noise regulations is required.

Further development of the approach proposed herein will focus on enhancing the ADS-B data pre-processing algorithm for higher efficiency and accuracy, experimental verification of the method, and expanding the model to a multi-objective optimization framework, incorporating operational scenarios and effective noise and emission mitigation strategies in airport vicinities.

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