

Dynamic Assessment of Airport Noise and Noise Abatement Procedures

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Abstract. To overcome the limitations of static airport noise assessment, this paper proposes a dynamic evaluation framework that integrates data-driven and simulation-based approaches. Based on ADS-B data, a two-stage clustering method is employed to extract representative flight trajectories. Noise simulation is conducted using the Aviation Environmental Design Tool (AEDT), and by integrating high-resolution population data, a spatial noise-population exposure model is constructed, enabling simultaneous fine-grained assessment of both the noise-affected area and the exposed population. The results show that NADP2 performs better in reducing the impacted area within the 70 – 80 dB range, whereas NADP1 achieves more pronounced noise reduction in high-noise regions above 85 dB. A key policy-relevant paradox is revealed: noise abatement procedures can reduce the overall noise-impacted area, yet may increase population exposure due to spatial redistribution of the noise field. This finding underscores the necessity of incorporating demographic data into dynamic airport noise management.

1 Introduction

The growth of civil aviation has intensified the impact of airport noise on surrounding communities. Traditional noise assessments, which rely on static flight tracks and standard procedures, often fail to capture the dynamic variations in real operations, leading to results that deviate from actual impacts [1]. The advent of surveillance technologies such as ADS-B has provided a data foundation for dynamic noise assessment based on real trajectories, thereby enhancing the realism of noise modeling [2].

Extracting typical patterns from real trajectories is essential for such dynamic assessments. While early clustering methods depended on Euclidean distance and struggled with temporal distortions, Dynamic Time Warping (DTW) and its variants have been widely adopted for measuring trajectory similarity and clustering [3,4]. Nevertheless, existing studies have predominantly focused on improving clustering algorithms, with limited systematic integration of the extracted representative trajectories into high-fidelity noise simulation and population exposure assessment. This has resulted in a discontinuity in the complete “trajectory-noise-impact” chain.

Furthermore, the focus in noise impact assessment is shifting from merely calculating physical sound levels toward a refined quantification of the exposed population. Although studies incorporating dynamic population models have improved assessment realism [5,6], effectively integrating such models with noise simulations driven by real trajectories remains a significant challenge.

To bridge these gaps, this paper proposes an integrated framework that links data-driven trajectory extraction, high-fidelity noise simulation, and dynamic population exposure assessment. The main contributions are: (1) a two-stage clustering method for extracting representative departure centerlines; (2) a spatial noise-population exposure quantification model; and (3) a systematic evaluation of how NADP1 and NADP2 procedures affect noise distribution and population exposure, thereby providing a quantitative basis for the dynamic and precise management of airport noise.

2 Research Methodology and Model Framework

2.1. Data Preprocessing

Building upon the ADS-B data foundation, a series of preprocessing steps were implemented to ensure data quality and consistency for subsequent analysis. The raw trajectory data were first deduplicated and then subjected to interpolation to achieve uniform temporal resolution. Smoothing techniques were applied to mitigate measurement noise, and abnormal points caused by signal loss or abrupt maneuvers were identified and removed. This rigorous preprocessing pipeline resulted in a high-quality dataset of departure trajectories, providing a reliable basis for clustering and simulation.

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2.2 Trajectory Clustering and Noise Procedure Parameterization

To evaluate the acoustic performance of different noise abatement procedures, typical departure trajectories were first extracted from ADS-B data. The raw data underwent preprocessing steps including deduplication, interpolation, smoothing, and removal of outliers to ensure quality and consistency.

A two-stage hierarchical clustering approach was then adopted to identify representative flight patterns. Initially, DBSCAN was applied to perform macro-level flow classification based on initial departure parameters (e.g., position and heading). Subsequently, within each macro-flow category, K-means clustering was employed on the spatial sequences of trajectories to identify geometrically similar sub-clusters.

The representative trajectory for each cluster is determined as the medoid using the standard Dynamic Time Warping (DTW) algorithm. Specifically, the actual trajectory that minimizes the sum of squared DTW distances to all other trajectories within the same cluster is selected. The use of standard DTW is appropriate since the analysis is strictly confined to departure-phase trajectories during preprocessing, and all trajectories are resampled to the same length of 100 points, thereby mitigating significant temporal misalignment. Furthermore, the medoid approach guarantees that the extracted centerline corresponds to an actual flown path, preserving operational authenticity. The corresponding mathematical formulation is given below.

$$T_{medoid} = \arg \min_{T_i, T_j \in C} \sum DTW(T_i, T_j)^2 \quad (1)$$

where C denotes the set of trajectories in the cluster. This method ensures that the extracted representative trajectory is an actual flown path from the dataset, thereby maintaining operational authenticity while effectively addressing temporal misalignment issues inherent in trajectory data (the overall process is illustrated in Figure 1).

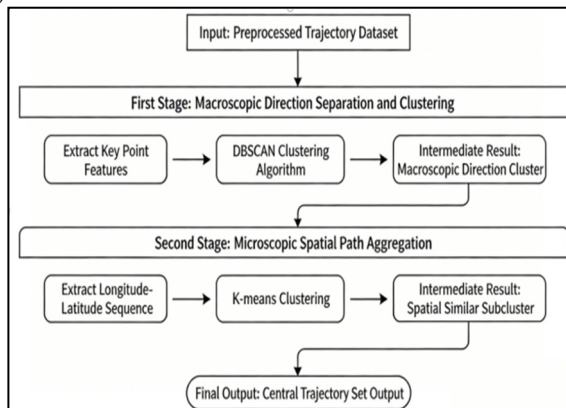


Fig 1 Flowchart of the two-stage trajectory clustering method.

The derived set of representative centerline trajectories was then imported into the Aviation Environmental Design Tool (AEDT) for noise simulation. By parameterizing key flight profile variables (such as thrust settings and flap schedules), three distinct departure

procedures were configured and compared within the simulation environment:

Standard Instrument Departure (SID): Served as the baseline.

Noise Abatement Departure Procedure 1 (NADP1): Characterized by thrust reduction at a relatively low altitude (≥ 800 ft) with delayed flap retraction, aiming to displace high-intensity noise away from areas near the runway.

Noise Abatement Departure Procedure 2 (NADP2): Characterized by an initial high-thrust, steep climb to gain altitude rapidly, followed by thrust reduction at a higher altitude, aiming to reduce the overall exposure time over the ground.

This workflow established a coherent and reproducible pipeline from real-world trajectory data extraction to the comparative assessment of multiple noise abatement procedures.

2.3 Integrated Assessment Model: Noise Impact Area and Population Exposure

To comprehensively assess the physical and social effects of the noise reduction program, this section constructs an integrated evaluation model, which analyzes the area affected by noise and the population exposed in parallel, aiming to reveal the potential correlations and divergences between them.

2.3.1 High-Fidelity Noise Simulation and Impact Area Extraction

The extracted centerline trajectories were imported into the Aviation Environmental Design Tool (AEDT) to perform high-fidelity noise simulation. By configuring the corresponding aircraft type, thrust settings, and flight procedures (Standard, NADP1, NADP2), the Effective Perceived Noise Level (EPNL) was computed for each monitoring grid point. Upon completing the simulation, AEDT's built-in spatial analysis engine can directly output the noise contours corresponding to different EPNL thresholds (e.g., >70 dB, >75 dB) and their associated impacted geographic area. This data is generated by the software based on its high-precision acoustic model and geometric calculations, serving as a core metric for evaluating the physical effectiveness of noise abatement procedures.

2.3.2 Spatial Overlay and Population Exposure Calculation Model

To assess the social impact of noise, we constructed an external spatial overlay model. First, the discrete EPNL monitoring point data generated by the AEDT simulation was interpolated to create a continuous noise raster surface, $N(i, j)$, matching the simulation area. Subsequently, this noise raster was rigorously aligned in space with high-resolution population distribution raster data $P(i, j)$, sourced from the WorldPop project. For a given noise threshold T_k , a binary mask $M_k(i, j)$ is

generated to identify areas where the noise level exceeds the standard:

$$M_k(i, j) = \begin{cases} 1, & N(i, j) \geq T_k \\ 0, & N(i, j) < T_k \end{cases} \quad (2)$$

The total population P_k exposed to noise levels above this threshold is calculated through raster overlay:

$$P_k = \sum_{i=1}^m \sum_{j=1}^n P(i, j) \cdot M_k(i, j) \quad (3)$$

3 Results and Analysis

3.1 Representative Trajectories and Noise Contours

In this study, runway directions are denoted following the conventional naming scheme based on magnetic heading (rounded to the nearest 10 degrees). For instance, operations departing to the north on the physical runway 18R/36L are represented as "36L" in the analysis and figures. This convention is applied consistently to all runway mentions hereafter.

The two-stage clustering method effectively identified dominant departure patterns. Figure 2 visualizes the extracted centerline trajectories (Medoids) for several major flows, confirming the method's capability to distill real-world operational variability into representative spatial paths.

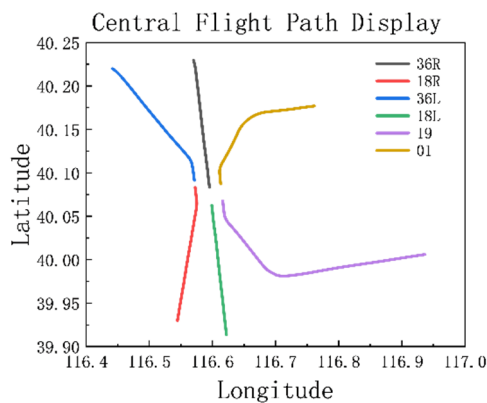
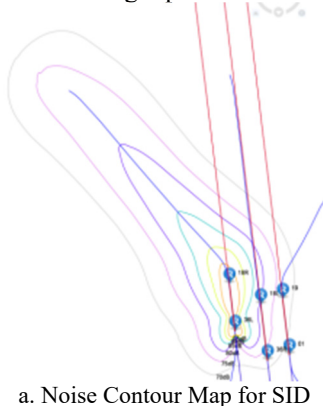
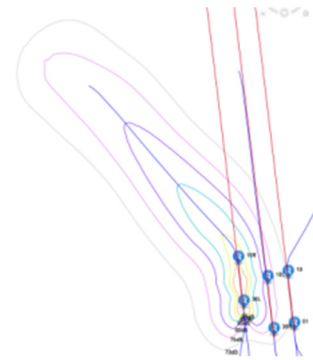


Fig 2 Central Flight Path Display

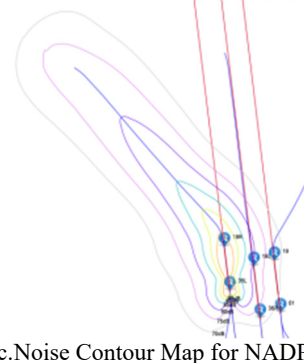
Building upon these representative trajectories and conducting simulations in AEDT under different flight procedures (SID, NADP1, NADP2), Figure 3 presents, using Runway 36L as an example, the noise contours generated by the three flight procedures.



a. Noise Contour Map for SID



b.Noise Contour Map for NADP1



c.Noise Contour Map for NADP2

Fig 3 Noise Contour Map(36L)

3.2 Analysis of Noise Impact Areas

The physical acoustic impact was quantified by the noise-affected area at various thresholds. Table 1 presents the results for Runway 01,36L, with consistent trends observed across all runways.

Table 1 Noise impact area under different takeoff procedures (unit: km²)

Run way	Noise impact (dB)	>70	>75	>80	>85	>90
01	SID	210.1	120.4	55.3	24.2	10.5
	NADP1	207.9	118.9	53.6	22.1	7
	NADP2	199.8	113.3	50.8	21.5	9.5
36L	SID	210.5	120.8	55.5	24.1	10.4
	NADP1	208.1	118.9	54.0	22.0	6.8
	NADP2	199.9	113.7	51.0	21.4	9.4

analysis confirms a clear functional distinction. NADP2 is more effective in reducing the impacted area within the medium-to-low noise range (70-80 dB), achieving a 5.0%-8.1% reduction compared to SID, attributable to its steeper initial climb. Conversely, NADP1 excels at mitigating high-intensity noise near the runway, reducing the area above 90 dB by approximately 33%-35%, leveraging its early thrust reduction strategy.

3.3 Population Exposure Assessment Results

The social impact was evaluated by calculating the exposed population using the spatial overlay model. Table 2 shows results for two representative runways (01 and 36L).

Table 2 Population affected by noise under different takeoff procedures

Runway	Noise impact (dB)	>70	>75	>80	>85	>90
01	SID	573265	354420	176534	71856	12337
	NADP1	544008	324949	171575	76653	5300
	NADP2	541329	321943	156029	62653	9932
36L	SID	434755	290230	163080	74478	24554
	NADP1	411329	270412	148196	61165	13636
	NADP2	412378	274259	149597	63922	21879

Based on the data from Table 1 and Table 2, the "area-population" divergence phenomenon is mainly reflected in the following two aspects:

1. Inconsistency Between Noise Reduction Effects and Actual Population Exposure

For example, in the >85 dB range for Runway 01, although the affected area under NADP1 (22.1 km²) is smaller than that under the standard procedure (24.2 km²), the exposed population (76,653 people) is actually higher. This indicates that noise abatement procedures may shift the noise impact to more densely populated areas. Therefore, the evaluation and implementation of noise reduction measures should not rely solely on the reduction in geographical area; population exposure must also be considered.

2. Need for Comprehensive Trade-offs in Selecting Noise Abatement Procedures

In the critical >85 dB high-noise range, while NADP2 performs better than NADP1 in terms of affected area, on Runway 36L, the exposed population under NADP1 is significantly lower than under NADP2. This suggests that there may be a deviation between the actual social impact (population affected) and the theoretical acoustic effect (size of the affected area). Traditional assumptions based on design principles may carry risks. The selection of noise abatement procedures should be based on a specific analysis of the "area-population" relationship for particular runways and noise thresholds, ensuring precise alignment between noise reduction objectives and the actual needs of community protection.

4 Conclusions and Outlook

This study proposes an integrated dynamic assessment framework that links real trajectory data, high-fidelity noise simulation, and fine-scale population distribution. This framework enables spatially explicit evaluation of both acoustic impact and population exposure, moving beyond conventional noise-contour analysis.

Results show a clear functional distinction: NADP2 better reduces medium-to-low noise levels (70 - 80 dB) over broader areas, whereas NADP1 is more effective at suppressing high-intensity noise (>85 dB) near the runway.

A key policy-relevant paradox emerges: an optimized noise abatement procedure can shrink the overall noise-affected area yet increase the number of exposed residents due to spatial redistribution of the noise field. This highlights that acoustic performance alone is insufficient to assess community impact; integrating high-resolution

population data is essential for equitable and sustainable noise management.

The proposed framework provides a quantitative, data-driven foundation for airport noise control and operational planning. Future research should further develop and extend this framework in the following directions: first, real-time ADS-B trajectory streams and short-term meteorological data can be integrated to achieve near-real-time prediction of noise impacts; second, intra-daily or seasonal dynamic population distribution models can be incorporated to more accurately assess the temporal characteristics of exposed populations; third, embedding this assessment framework into airport collaborative decision-making systems could be explored to provide online decision support for balancing noise-population exposure trade-offs under various operational scenarios, such as runway configuration and arrival/departure procedure selection.

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